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Mapping tomorrow's resources: a symposium on the uses of remote sensing, geographic information systems, and global positioning systems for natural resources management

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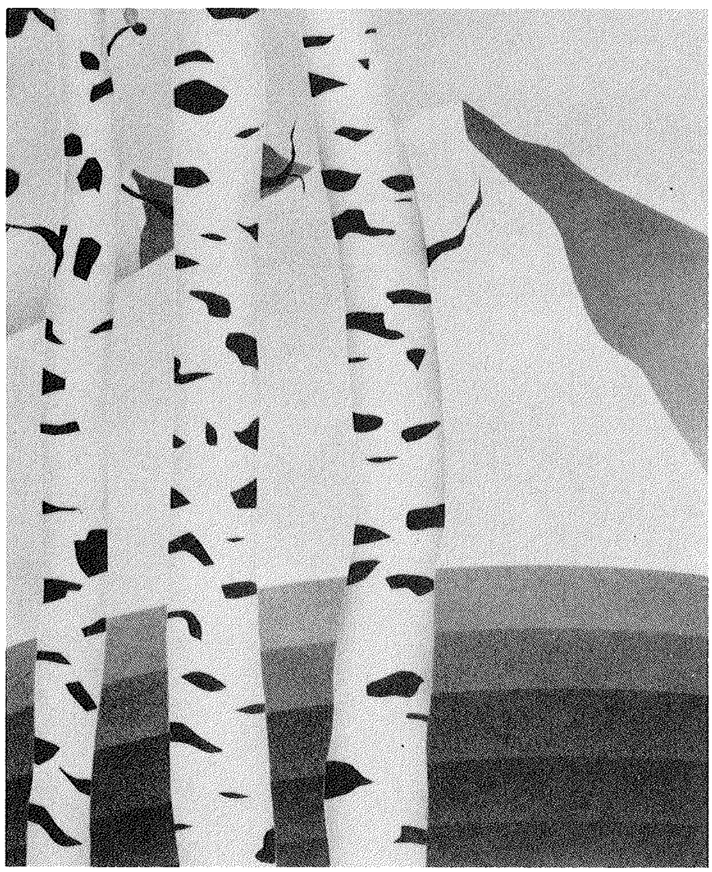
Mapping Tomorrow's Resources

A Symposium on the Uses of Remote Sensing, Geographic Information Systems (GIS), and Global Positioning Systems (GPS) for Natural Resources Management



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Foreword

The College of Natural Resources recognizes the important role it has in educating natural resources managers and leaders who can provide the guidance and knowledge needed to increase the production of the earth's renewable resources while sustaining and enhancing the global environment and the natural resources base. The College's teaching, research, extension, and service efforts focus on the many aspects of sustained multiple-natural-resources management and their relationship to man. Through its many programs, the College of Natural Resources focuses on solving local, state, national, and global problems to enhance a more efficient and contemporary use of the world's natural resources.

Since 1930 the College of Natural Resources has offered several publications of various kinds to disseminate technical and popular information about natural resources and the environment. These publications have included *The Utah Juniper* (1930–1970), which started as a technical publication and evolved into a popular format and ultimately into the College's yearbook; *The Edge* (1978–1980), which was intended to be popular in format and highlighted faculty research efforts; and most recently, *Resource Lines* (1989–present), a newsletter about the College of Natural Resources and its programs, faculty, students, alumni, and friends.

The publication begun in 1993, *Natural Resources and Environmental Issues (NREI),* is a technical series that addresses current topics relevant to natural resources and to the environment. The journal is published as a series of volumes, with at least one being issued each year as the proceedings of the Natural Resources Week Symposium. Publication in *NREI* is by invitation only.

The management of global natural resources depends on our ability to obtain and disseminate pertinent information in a timely manner. Equally important, the information should reflect current issues of concern to natural resources and environmental managers as well as to the public. Through *NREI* the College of Natural Resources will provide information on timely topics of broad concern to professionals and to society as a whole.

Joseph A. Chapman, Dean
College of Natural Resources

Proceedings of the Symposium

Mapping Tomorrow's Resources

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Geographic Information Systems (GIS),
and Global Positioning Systems (GPS)
for Natural Resources Management*

Edited by
Allan Falconer

College of Natural Resources, Utah State University
Logan, Utah

This volume is the result of the symposium held April 23-24 during College of Natural Resources Week, an annual event on the campus of Utah State University.

1992 Symposium Planning Committee

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Introduction

Mapping tomorrow's resources is an essential step in the planning of our future. Natural resources by definition occur in a specific location, merely another way of stating the obvious: Everything has to be somewhere! In this age of information technology, systems have been developed that store information electronically by location so that it can be retrieved rapidly. The value of the systems lies in their ability to respond to geographic location queries as fast as possible. However, the system is not productive unless the information itself is accurate and can be used with confidence.

In natural resources studies, there has always been a problem with location information because the location of resources is important information. Ultimately, location defines ownership or access to mineral wealth, timber resources, water resources, or other marketable commodities. The problem has been the need for accuracy and the need to relate the accurate resources information to specific ownership data. Controversy over accuracy, ownership, and exploitation rights increases with the value of the commodity. Controversy is increased if the commodity is valued for its cash return by one group and for its scenic beauty by another group. Competing claims for the superior value of one assessment over the other underlie much of the present debate about the use of public and private lands.

Providing information for decision-makers who must resolve these controversies is an important requirement. The same information can be of critical importance to managers and planners responsible for tomorrow's resources. Typically, natural resources information was recorded on manuscript maps or published maps. In both cases, the map compilation process created a significant time delay between data collection and product availability. Such maps are difficult to modify and reinterpret, and the direct link between the position shown on the map and the location on the ground is not always easy to establish.

Geographic information handling has improved rapidly in the last decade. Systems of computerized mapping, satellite-based location systems, and satellite systems viewing the earth's surface known as geographic information systems (GIS), global positioning systems (GPS), and remote sensing, respectively, have all become available to natural resources scientists. In each case, the system and the concept of the system have become generally known. However, it is only in recent years that the speed and capacity of affordable computer systems have reached a level where appropriate software systems can be reliably implemented.

It is convenient to group the three systems—GIS, GPS, and remote sensing—together as geographic information technology. Technology has now reached a point where location can be precisely determined in a matter of seconds. This permits the positive definition of location for field data collection. Data collected with precise location parameters can then be accurately plotted on a map by entering data in a GIS. Natural resources data plotted in this way can be registered to a remotely sensed image to compare the field information with the satellite overview.

Current computer power is sufficient for GISs to operate interactively so that new map compilations can be presented on the screen in a few seconds rather than in the tens of minutes or hours previously required.

Software is using the greater capacity of the current generation of computers to add capability and to improve performance. The result is a series of programs that efficiently record, enter, store, manipulate, and map geographic information.

When natural resources information is entered, these systems become a powerful tool for natural resources research and a great benefit to the managers of natural resources. This symposium was designed to bring together leading figures in GIS development with the leaders in remote sensing and data collection to address the topic of natural resources.

Mapping tomorrow's resources requires both the technology and the wisdom to put the technology to use. This collection of papers illustrates the technology and outlines the direction of its development. It also illustrates the diversity of applications in natural resources. Management of natural resources is a topic of current concern among government agencies at the federal and state levels. In particular, applications to conservation, biodiversity, and the management of public lands are significant areas of activity.

The national overview of biodiversity provided by the Gap Analysis project on a state-by-state basis will be a significant contribution to the understanding of the nation's biological resources. This project draws on geographic information technology and brings together the activities and products from federal and state programs. Future data from NASA's earth resources satellites will contribute to this project. Existing programs illustrate the power of the technology at local, national, and global scales.

Operational use of geographic information technology for mapping forest resources in the Pacific Northwest needs to be integrated with global systems for forest data. Training to ensure that staff can use the data and to ensure that databases are maintained is an important requirement. Other uses of the data by land-management agencies and the integration of georeferenced data into the system require an understanding of global positioning systems and the agency programs.

New systems of data collection and new developments in software all have to be considered as planners and managers design for the future. In order to map tomorrow's resources, managers will require increasing knowledge of geographic information technology. The technology can provide great benefits if it is used to provide information in a timely and comprehensive manner. If the challenges of natural resources management are to be met, the next generation of graduates must have the background and the knowledge to gather pertinent data for decision-making.

The College of Natural Resources has concluded that geographic information technology is an essential component of natural resources research and development. Accordingly, it has invested in a new remote sensing/GIS laboratory and has become a willing participant in the training and project work. The 1992 Natural Resources Week symposium proceedings recorded here represent the first step in establishing this program at Utah State University. It was a pleasure to share the College's vision with so many of the leaders in the field of geographic information technology during the symposium, and it is a further pleasure to share these proceedings with you.

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Natural Resource Information

From Monopoly to Competition

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Abstract

Geographic information systems and remote sensing technologies have been rapidly adopted in many sectors of the natural resource field. Falling hardware prices and ever more powerful yet easier to use software have not only reduced the cost but have also broadened the accessibility of these technologies.

Technological advances are making the generation and use of resource information a competitive process. Whereas in the past public resource agencies alone had the data and analytical capability to prepare resource-management plans, today GIS technology can give a small group of knowledgeable and motivated users the power to replicate those analyses and to propose defensible and scientifically rigorous alternatives. Examples are given of forest management practices that were successfully challenged in this way.

The past decade has seen an explosive growth in GIS technology and a less dramatic but important acceptance of remote sensing technology. The rapid incorporation of these technologies into the natural resources field is due to a number of driving forces that have together made their adoption imperative.

During the past decade, the power and accessibility of computer software and hardware have increased by orders of magnitude while prices have steadily fallen. The $10,000 workstation, small enough to sit on your desktop, is more powerful than the million dollar minicomputers of 1980.

Software has become much easier to use. Developers of business software for the personal computer (PC) recognized early on that there was an enormous market for full-featured software that nonprogrammers could use. Fortunes have been made satisfying this demand, and in the process the man/machine interface has developed steadily in the direction of simplifying the control of ever more complex tasks. Today's spreadsheet programs, costing $300-$400, can do sensitivity analyses, optimize complex financial models, produce high-quality graphics dynamically linked to the data, and import and export data from external databases. They are easy to learn, and a novice can begin doing useful work in a matter of hours. The experience people gained with business software for the PC has led them to expect sophisticated software to be ever more user-friendly as well.

GIS and remote sensing software has followed suit. Though full-featured software may still require weeks of use for the novice to become proficient, these systems can be tailored with custom menus and routines so that standard tasks can be learned in a few hours. There are now dozens of inexpensive PC-based remote sensing and GIS software packages with user-friendly graphic interfaces. The past year has seen the introduction of GIS "viewing" software. These are inexpensive GIS packages offered as companion products to more complex full-featured systems. For example, Environmental Systems Research Institute (ESRI) has introduced ArcView to work with GIS databases produced by ARC/INFO, and Intera-Tydac introduced SPANS MAP to work with GIS databases produced by SPANS. These viewing products are designed to be very easy to use; and they offer sophisticated displays of map, image, and tabular data. They provide a wide range of query functions but limited analysis capability. Products such as these are a continuation of the trend toward GIS and remote sensing software becoming easier for the casual user to operate effectively and at lower cost.

During the past decade, society has become more concerned about the environmental consequences of development activities. There is growing concern for the scarcity of resources, such as clean air and water, prime agricultural land, and wildland areas. Headline-grabbing events, such as the explosion of the Chernobyl nuclear power plant in the Soviet Union, global warming, destruction of the Amazon rain forest, and the discovery of a hole in the ozone layer, have sensitized the public. The lifting of the Iron Curtain has revealed the severe pollution in Eastern Europe and the human health problems caused by industrial waste. Recognizing and understanding these issues and predicting their consequences require the compilation and analysis of large quantities of geographically referenced data. GIS and remote sensing technologies are now recognized as instrumental in identifying, monitoring, or analyzing these problems.

Western society has become more complex. Growing public concern over the widespread and diverse effects of development activities has led to more government regulation. Issues are now seen to be intertwined. For example, stricter regulations to protect endangered species may decrease employment in the logging industry, change procedures for road construction, affect tourism, and change import regulations. The application to build a new subdivision can involve agencies at the municipal, regional, provincial, and even federal levels of government. In addition, the increased public awareness of diverse and often subtle environmental interactions has made people feel that they are directly affected and have a stake in a wider range of issues. This perception has increased the number of stakeholders who are willing to take action to protect their interests. As a result, decisions involving land have become much more political. For example, forest harvest activities may be scrutinized by conservation groups, hunting and fishing interests, the local tourist industry, municipalities, native communities, and even citizens groups from outside the country, in addition to government regulatory agencies. Decision-making about land-related activities now requires more interaction with a more diverse group of organizations than before. In this complex political and regulatory environment, GIS and remote sensing technologies have proven to be cost-effective tools with which to develop and refine plans, to produce the documentation required by regulatory agencies, and to communicate with the public.

These forces have led to the adoption of computer technology on a broad scale. Once a luxury, computers have now become a necessity for managers, knowledge workers, and administrative staff. The technology has provided the tools with which to handle the volume and complexity of information they need to do the job. In so doing, decision-making capability (though not necessarily authority) has been driven lower down in the organizational hierarchy.

Among the benefits of GIS and remote sensing technology are the following:

1. Doing more in less time with fewer people.

2. Integrating large and diverse spatial data sets, enabling more factors to be considered in the planning and design of land-related activities. The technology makes a broader, more holistic scope financially feasible.

3. Using the modelling capabilities of GIS and high-speed processing to enable more alternatives to be considered (and iteratively refined) than were affordable using manual methods.

4. Utilizing GIS technology to empower an individual to work effectively with large quantities of diverse spatial data.

INFORMATION POWER TO THE INNOVATIVE AND THE COMMITTED

The growing adoption of GIS technology has been accompanied by the rapidly increasing availability of digital data. Government agencies in the United States offer elevation data, satellite imagery, street networks, electoral districts, land use and land cover, and many other data sets in digital form at nominal cost. Private firms, such as Etak, have entered the digital-data market to offer additional products or enhanced versions of government products. The availability of inexpensive data and inexpensive easy-to-use computer hardware and software has put the start-up and operating cost of a GIS and remote sensing facility within reach of small organizations.

Whereas in the past large organizations controlled the data and analyses because equipment was very expensive and a large staff was needed to perform analyses, now these data can be obtained in digital form and analyzed by a few dedicated individuals using inexpensive personal computer equipment. It is now feasible for a special-interest group to obtain the computer resources, data, and trained people to perform analyses with a level of scientific rigor and sophistication equal to those produced by the government agencies that administer natural resources. In addition, these small groups are not constrained by bureaucratic procedures, compartmentalizing of resources (e.g., remote sensing and GIS are done in different departments), restrictions on purchasing additional resources (e.g., not permitted to purchase additional software without approvals), and so on.

They can be as creative as they wish, obtaining data from the field or from other sources as needed and making data-sharing arrangements with outside organizations, free of bureaucratic constraints.

As a result, special-interest groups, citizen advocacy groups, and others are able to scrutinize the decision-making of government organizations in a much more comprehensive and rigorous manner. They are able to conduct their own research, field work, and analyses at a comparable or even superior level of quality and rigor. In so doing, they can not only ask whether alternative plans were considered, they can analyze those plans and develop alternatives using the same superior methods as the organization they challenge.

The responsibility to administer natural resources no longer grants an organization exclusive control and use of the information it generates. Analysis of the data is no longer dependent on prohibitively expensive equipment or on a large number of people. A small group of three or four talented individuals can evaluate land-use plans and develop defensible alternatives to challenge the administering agency. In effect, what had been the exclusive domain of natural resource agencies has now become a competitive process.

Where information generation and use become a competitive process, there is a significant premium to being creative, competent, and committed, especially in a rapidly changing political environment. Public decision-making that involves environmental issues takes place in the context of constantly changing political realities, scientific understanding of ecological processes, and financial and human-resource constraints. In 1990 Steve and Eric Beckwitt used their GIS and remote sensing analyses to appeal the U.S. Forest Service plan to log old growth in Tahoe National Forest. The quality of their data analysis and presentation of results were instrumental in the success of their appeal. Other West Coast citizen advocacy groups, such as the Greenbelt Alliance in San Francisco and the Wilderness Society in San Francisco, have also used this technology to support their causes.

In Canada, native communities are adopting GIS and remote sensing technology to assist them in developing land-claims proposals, in defending their land-related interests before and after land claims are settled, and in managing their lands. Recent land claims, such as the first James Bay Agreement and the Inuvialuit Claim, have given aboriginal people control of natural resources over large areas. These agreements stipulate specific management responsibilities, such as wildlife management (including the census of populations and setting of harvest quotas), the review of environmental and cultural effects of development activities (e.g., mining and forest harvesting), and the provision of community services (e.g., education and basic infrastructure, such as water and sewage).

Native communities are rapidly adopting GIS and remote sensing technology to gain control of the information about their current land holdings or the land they claim. Applications range from environmental assessments of mega-projects, such as the James Bay II hydroelectric project in Quebec, to local projects, such as the management of wild mushroom production.

In northern British Columbia, wild mushrooms are an important cash crop for native communities, such as the Nisga'a. Favorable mushroom sites can be identified by a combination of forest cover, elevation, and aspect. The Nisga'a have a PC-based GIS and remote sensing facility operated by two full-time staff. They analyze Landsat satellite data to develop a vegetation classification; and then within a GIS, they combine these data with elevation and cultural features. The results are used to define prime growing sites. These areas are then protected from forest harvesting and are used to plant and harvest mushrooms.

The Manitoba Keewatinowi Okimakanak (MKO) is an organization representing twenty-three native Indian bands in northern Manitoba. In 1988 the MKO established the Natural Resource Secretariat (NRS) to provide in-house research and information management for the natural resources upon which the MKO member bands have traditionally relied and upon which they will base their future economic initiatives. The acquisition of GIS and remote sensing technologies was central to the NRS facility, which has a staff of four and $65,000 of computer hardware and software. Start-up of the facility was financed with government funding to support MKO's participation in the environmental assessment for a proposed hydroelectric development. Instead of contracting out the work, the MKO used the project to set up a facility of its own and to develop the capability to collect and analyze resource information.

The MKO facility uses SPOT and Landsat satellite data, existing digital map data, and aerial photography to monitor and challenge forest harvest activities and road construction in the lands they claim. The GIS is being used to map the lands occupied and used by member bands in support of future land claims. With the support of the band council, the staff of the GIS facility interviewed every member of the community who harvested resources from the land through hunting, fishing, or trapping. Staff members also inventoried culturally significant places such as burial sites. These data formed the core database of information about the community's land-resource base. When organized within a GIS, it provided an effective means with which to defend its interests. The MKO has found that through its creative use of remotely sensed data and GIS methods it is able to generate more current and accurate information than the provincial resource agencies with which it negotiates. It has been able to successfully challenge forestry operations by analyzing such features as the location and number of roads built, size and number of cut-blocks, and location and timing of harvest operations.

In 1989 extensive forest fires raged through northern Manitoba. One fire burned to the edge of an MKO community. Claiming that the Manitoba Forest Service had been negligent in controlling the fire, the MKO sought compensation for the loss of facilities in the vicinity of the settlement as well as for the many widely scattered trapping cabins. In a matter of a few weeks, the GIS facility produced maps from satellite imagery, showing the extent of burned areas. It also identified by aircraft overflights which cabins had been destroyed, and it produced individual claims for each trapper who had lost property.

A small group can successfully advance its cause with high-quality information products generated by talented and committed individuals using low-cost equipment and data. The advantage over a large bureaucracy lies in the people who power these facilities and who are dedicated to their cause. In the case of native people, they see the defense of the lands they claim as a matter of survival. These facilities are staffed by small groups of individuals directly involved in the group's success or failure. There is little bureaucracy to constrain unorthodox but promising approaches. Creativity can be easily accommodated. The objectives of these groups are clearly defined; they know their mission and are fully committed to it.

CAN GOVERNMENT RESOURCE AGENCIES LEARN FROM THE CITIZENS' GROUPS WHO CHALLENGE THEM?

Techniques to raise morale and to generate commitment within large organizations have been extensively discussed in the business literature. Of particular note are the following observations.

There are many operational GIS activities that require a strictly prescribed series of tasks. Transaction processing, for example, demands that data be entered in a rigorously controlled manner. However, when the unusual or unexpected occurs, it is the creative and competent individuals familiar with the capabilities of the organization's information systems who can quickly develop new information products to respond to the challenge. In order to develop these systems, organizations must give individuals the time and the freedom to experiment, to try different analysis approaches, and to work with a variety of software products. Organizations need to stimulate and reward goal-directed experimentation and creativity.

An organization's data is the foundation of its operation. If it is not standardized, the organization's effectiveness is compromised. However, standardization should not be religiously extended to the tools the organization uses to work with its data. By allowing some experimentation with alternative data analysis tools (e.g., GIS software), the organization promotes the infusion of new ideas and develops alternative analysis approaches and capabilities. In so doing, in-house users develop a diversity of skills that can be invaluable when a quick response to a new situation is needed.

Diversity is further enhanced if users can be organized into small groups with diverse expertise, i.e., remote sensing specialists should not be isolated from GIS specialists. In assigning different specialists to work together as a team, there is an opportunity to develop a working knowledge of related specialties and to find new ways of optimizing the combined use of their expertise and technology.

There is an important role for creative individuals with a talent for GIS and remote sensing analysis. They are demoralized by constraints on their inquisitiveness and are easily frustrated by weak managers unwilling to try the new and unproven. Yet it is these individuals who provide the talent to keep pace with unexpected and rapid changes. Organizations must learn to channel the energy of these individuals into productive activities instead of reining them in. The mavericks have the energy and imagination to handle the unpredictable. In order to compete successfully with small, committed special-interest groups equipped with GIS and remote sensing information technology, large organizations need the same kind of creative talent, initiative, and competence that these small groups naturally attract.

CONCLUSION

Rapid advances in GIS and remote sensing technologies have made it less expensive for a committed group to defend its interests successfully and more expensive and difficult for a large organization to keep up with these groups. Rapid changes in the political arena, in the technology, and in the availability of information have created a situation in which a small group can outmaneuver a large organization by working more quickly and by being more creative. As the pace of change increases, a small resourceful group is increasingly favored. In order to keep up, large organizations need to create the dynamic and productive work environments that small groups provide. The recent management literature has reported extensively on the merits of this type of approach, i.e., intrapreneurship, and has encouraged champions to push new ideas through the corporate bureaucracy. Encouraging individual initiative is critical to maintaining the competitiveness of the corporation.

Government agencies responsible for natural resources have traditionally not seen their role as an administrative, research, and regulatory function in the public trust. GIS and remote sensing technologies have fundamentally changed this role. By enabling small groups to challenge the information and resource plans generated by these agencies, they serve, in effect, as competitive sources of information and plans for the use of resources.

In the corporate world, the first place to look for successful ideas is at successful competitors. In the same way, when resource agencies find themselves outmaneuvered by small special-interest groups that generate more accurate or more current information, the agencies would do well to learn how these small groups acquire and maintain their talent, resources, and commitment to success—then emulate them.

Global Resources and Mission to Planet Earth

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Abstract

The NASA contribution to the U.S. Global Change Research Program is termed the Mission to Planet Earth. Components of the Mission to Planet Earth, such as the Upper Atmosphere Research Satellite (UARS), have already been flown; and several other satellites will be flown in the next few years. The major component of the Mission to Planet Earth is the Earth Observing System (EOS) scheduled for initial launch in 1998. Considerable volumes of valuable data will be stored and made accessible through the EOS Data and Information System (EOSDIS). These data will not only be useful for earth-science research but also for resource monitoring efforts and environmental impact studies. The challenges in making these data available are to provide the technologies and infrastructure to make them accessible to scientists, resource managers, and decision-makers in a timely and cost-effective fashion. In addition, students must be trained and given the background to make optimal use of remotely sensed data, such as that forthcoming from spaceborne observing platforms.

INTRODUCTION

It has often been stated in various contexts that "the only thing that is constant is change itself." Certainly this is true about the distribution in space and time of processes occurring on the earth. In these times, it is becoming clear that besides the natural variability that occurs with increasing human population and the activities associated with this increasing population man has become a factor in changing earth processes such as climate. Because of the potential effect on life on this planet (Eagleson 1991, Lubchenco et al. 1991, Silver and DeFries 1990), international (International Council of Scientific Unions 1990, Houghton et al. 1990) and national efforts (Lashof and Tirpak 1990) have begun to understand global change, including anthropogenic effects. As an agency contribution to the U.S. Global Change Research Program (Committee on Earth and Environmental Sciences 1992), NASA has embarked on the Mission to Planet Earth (Wickland 1991). The characteristics of the U.S. Global Change Research Program are to be captured into three streams of activity. These are documenting global change (observations), enhancing understanding of key processes (process research), and predicting global and regional environmental change (integrated modeling and prediction). The intents and purposes of the Mission to Planet Earth are primarily scientific in nature and contribute substantially to the activities of the U.S. Global Change Research Program. The broad objective of Mission to Planet Earth is to determine the extent, causes, and regional consequences of global climate change.

The purpose of this paper is to describe briefly the components of the Mission to Planet Earth and to comment upon the applications, opportunities, and challenges associated with utilizing the data to be collected for environmental monitoring and resources management.

MISSION TO PLANET EARTH

Considerable data from spaceborne platforms have already been collected. These data comprise databases extending over a decade. In many instances, these databases offer a comprehensive and global view of vegetation dynamics, snow and ice cover, sea surface temperature change, variability in cloud cover and attendant properties, and the composition of the upper and lower atmosphere of the earth. These databases have come from such U.S. satellite missions and sensors as the Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS) with high spatial resolution; multispectral scanner data extending from 1972 to the present; and the NOAA operational satellite missions and such sensors as the Advanced Very High Resolution Radiometer (AVHRR) and the Tiros Operational Vertical Sounding (TOVS) unit, with comprehensive and relatively complete and consistent databases extending from as early as 1966 (snow cover) to the present. Data have also been gathered from the Nimbus Coastal Zone Color Scanner (CZCS) and the Scanning Multichannel Microwave Radiometer (SMMR) and the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI). Other nations or international organizations, such as the European Space Agency (ESA), France, and Japan, are also operating satellites that provide comprehensive and valuable observations of the earth on global and large regional scales. Most recently and notably, both ESA and Japan have succeeded in orbiting on free-flyer spacecraft Synthetic Aperture Radar (SAR) systems that provide high-spatial resolution, microwave (nearly all weather) views of the earth's surface.

Remote sensing from space has already laid the basis for the Mission to Planet Earth. In fact, it has become clear that a comprehensive and forthcoming understanding of earth processes on a global scale can only be accomplished through spaceborne remote sensing as indicated in previously referenced publications. These spaceborne observing systems complement existing in situ networks primarily by providing relatively uniform, nearly synoptic, high-spatial density, frequent views over large regions.

The Mission to Planet Earth has several main components as illustrated in Figure 1. The space components are called Earth Probes, Polar Orbiting spacecraft, and Geostationary orbiting spacecraft. The key ground component is the Data and Information System (DIS). The information from the DIS will lead to improved process studies, better global interactive models of the land/ocean/atmosphere system, and, subsequently, as understanding improves and confidence in the models improves, better assessment and predictions of the consequences of global change brought about by natural and anthropogenic influences.

The Mission to Planet Earth is already under way, and several missions will be forthcoming in the next five to six years. Already launched are the Upper Atmosphere Research Satellite (UARS) and the Atmospheric Laboratory for Applications and Science (ATLAS) payload on the STS-45 mission, which will look at the composition and evolution of chemical compounds in the upper atmosphere. Following soon are the earth-probe missions, such as the SeaWiFS/Seastar mission to observe ocean color and biomass, scheduled to be launched in 1993; the Total Ozone Monitoring missions beginning in 1994; and the Tropical Rainfall Measuring Mission (TRMM)

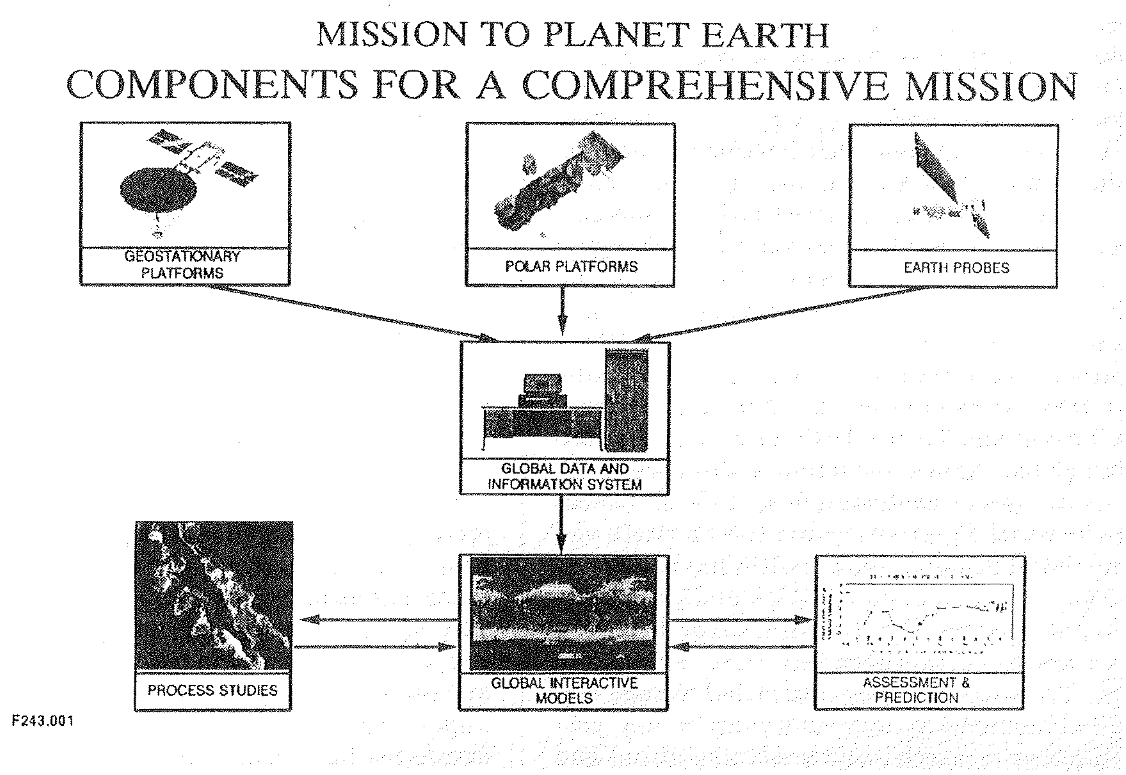

Figure 1

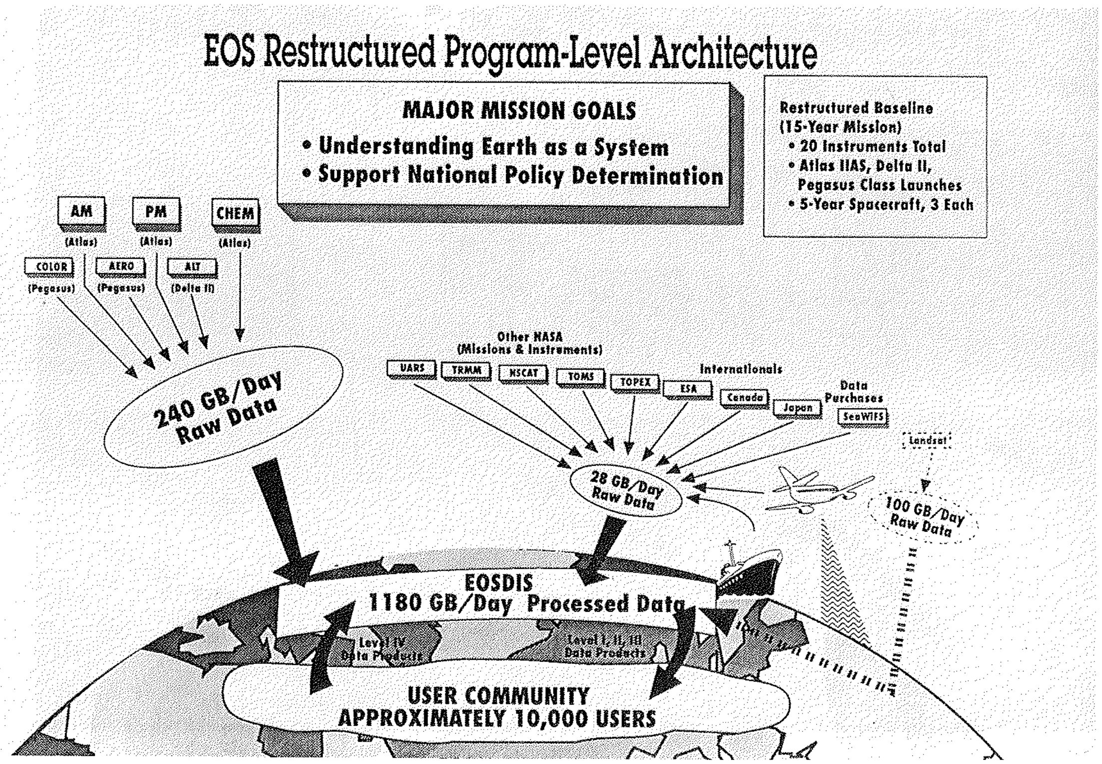

Figure 2. Schematic diagram depicting the extent of the EOS program including the amounts of data involved.

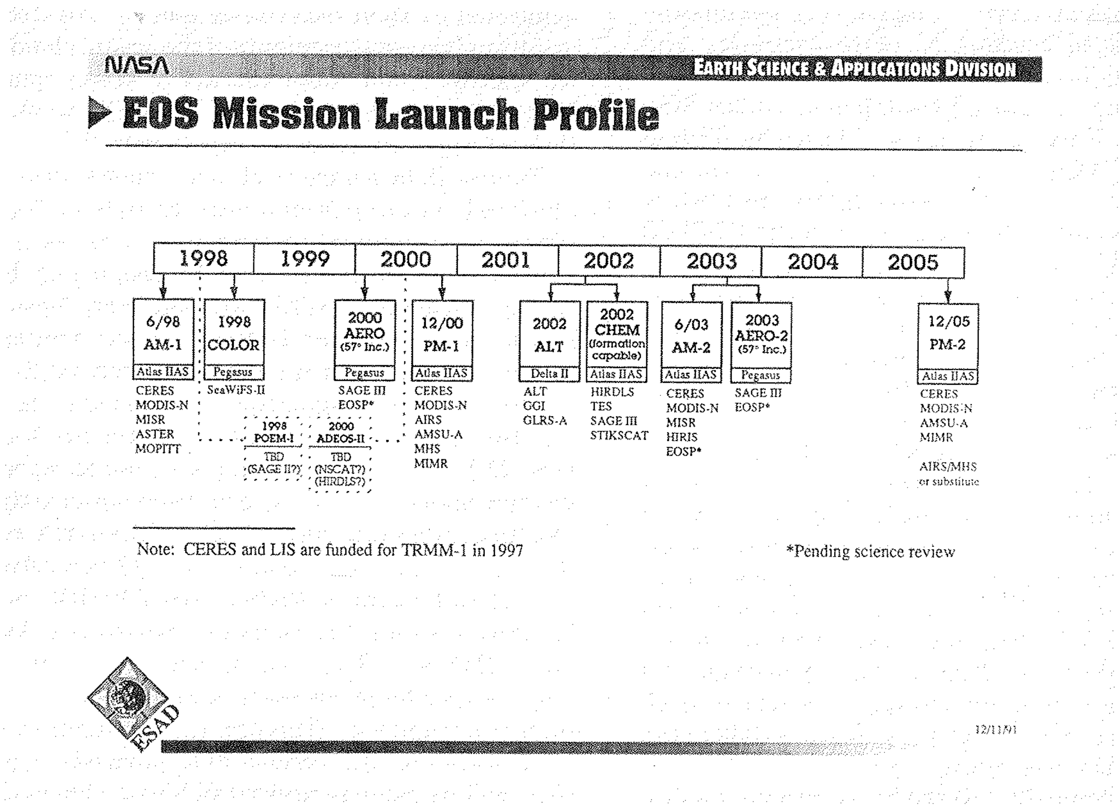

Figure 3. The launch sequence for the various EOS platforms.

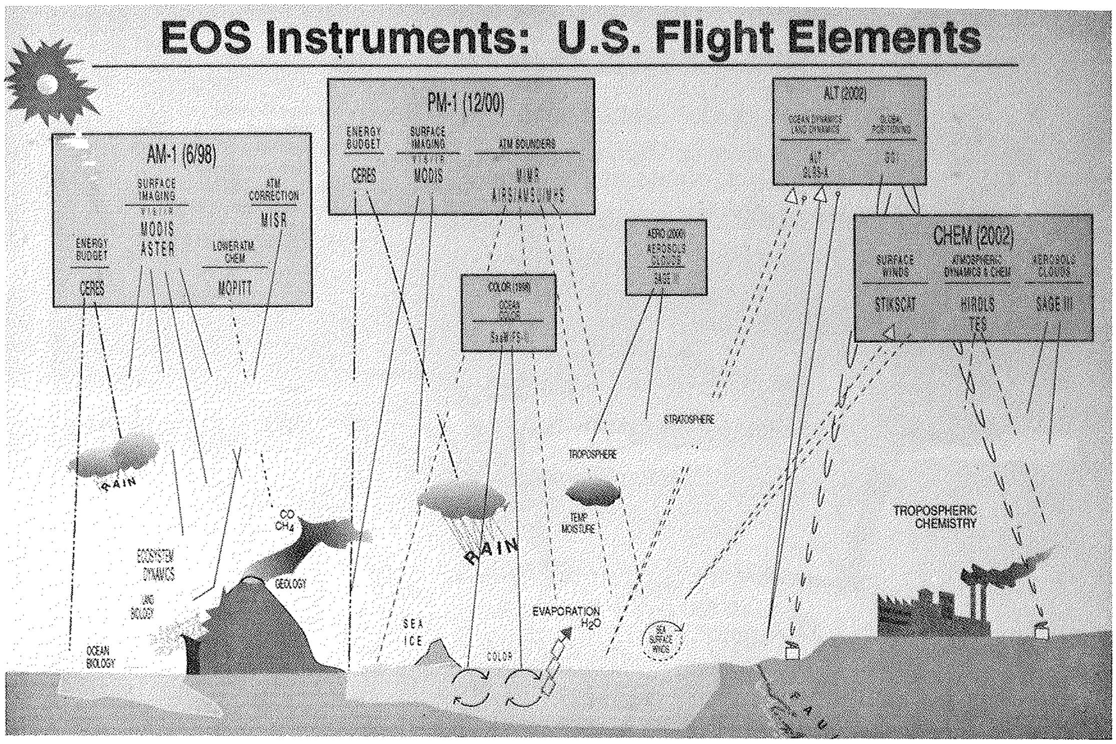

Figure 4. A diagram illustrating the broad observational intents of the EOS instruments.

scheduled for 1997. These missions will be complemented by Landsat 6 (1992), Landsat 7 (1997), and the Laser Geodynamics (LAGEOS 2) mission scheduled for launch in 1992, augmenting spaceborne contributions to studies of plate tectonics and macroscale motions of the earth itself.

The principal and largest component of the Mission to Planet Earth is the Earth Observing System (EOS) (Truly 1992). Figure 2 shows the various components of the EOS. This figure also offers insight to the data volumes going into the EOSDIS and eventually into the hands of the scientific and user communities. The challenge of acquiring, storing, and disseminating these data in a timely and user-friendly fashion is an imposing one. On the other hand, the richness of the data in terms of informational value promises to be very large.

Figure 3 shows the overall schedule for the launch of the EOS. The first component of the EOS is scheduled for launch beginning in 1998, with several payloads of varying size and composition to follow. The EOS components will eventually provide a fifteen-year data set of comprehensive and global remotely sensed data. The major platforms are the so-called A.M. and P.M. platforms. These platforms will cross the equator at approximately 1030 hours (local, solar time, descending daylight pass) and 1330 hours (local, solar time, ascending daylight pass). The A.M. platform is primarily devoted to observing surface cover dynamics, clouds, and radiation balance parameters. The P.M. platform will emphasize cloud cover, tropospheric temperature, and composition as well as land and ocean surface properties. The other platforms are more specialized in their contributions as suggested by their descriptive names: Alt (focusing on altimetric measurements of the ocean, clouds, and ice sheets); Color (observations of ocean color and biomass); and Chem (devoted primarily to observations of upper atmosphere constituents).

There will be a variety of instruments on the EOS platforms, ranging from relatively high-spatial resolution, multispectral instruments, such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the High Resolution Imaging Spectrometer (HIRIS), to lower spatial resolution, multispectral radiometers, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multispectral Imaging Microwave Radiometer (MIMR). Each of these instruments represents advancements over what has been previously successful in providing observations of the earth, such as the Landsat Thematic Mapper, the NOAA Advanced Very High Resolution Radiometer (AVHRR), and the Nimbus Scanning Multichannel Microwave Radiometer (SMMR). The instruments, of course, have various specific purposes that are schematically depicted in Figure 4. Through the applications of the instruments on the various EOS payloads, contributions will be made to understanding a wide variety of interconnecting processes on a global scale as depicted in Figure 5 (Earth System Sciences Committee 1988).

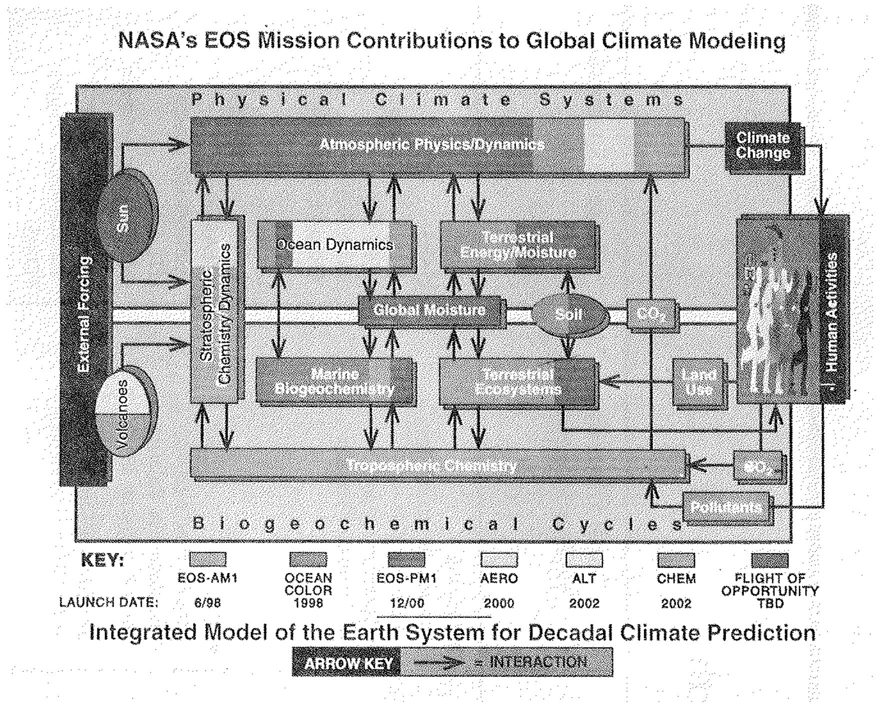

Figure 5. The contributions of the EOS platforms and attendant instruments to global climate monitoring.

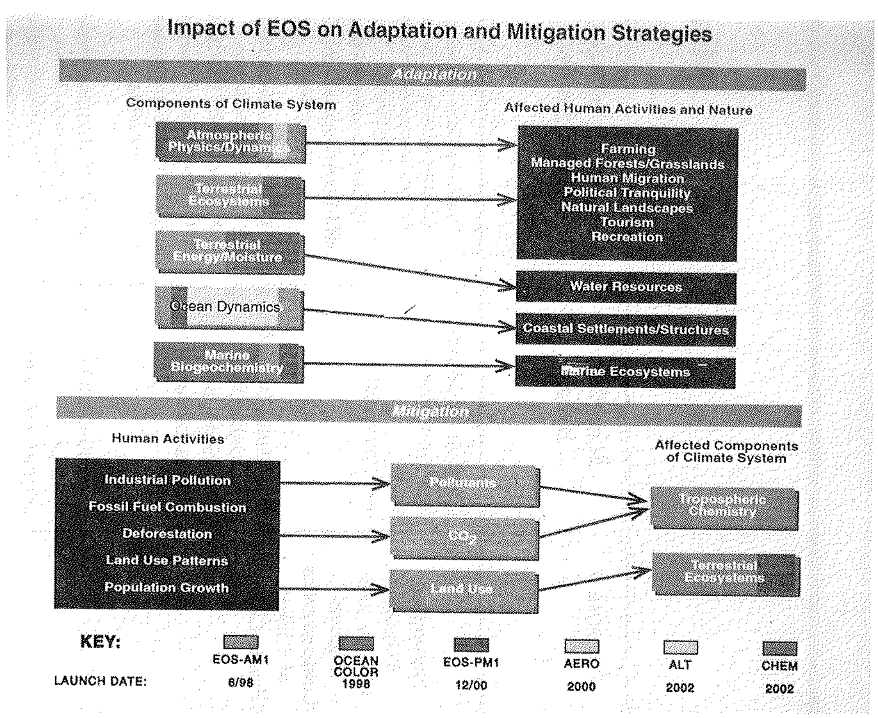

Figure 6. The relationship envisioned for EOS science as manifested on the various platforms and resource monitoring and environmental change activities.

Mission to Planet Earth

Purpose	Scientific Issues	Interdisciplinary Investigations	Distributed Active Archive Centers	Earth Observing System Spacecraft	Phase 1 Spacecraft
Determine Extent, Causes, and Regional Consequences of Global Climate Change	The Role of Clouds, Radiation, Water Vapor and Precipitation	LaRc-Radiation & Clouds Goddard Institute for Space Studies-Interannual Climate Variability NCAR-Climate Modeling MRI (Japan)-Atmos/Ocean/Land Interactions	•LaRC Radiation Budget, Aerosols, Tropospheric Chemistry	•EOS-AM -Clouds, Aerosols, and Radiative Balance -Characterization of Terrestrial Surface	**NASA** UARS Upper Atmosphere TOPEX/Poseidon (with France) Ocean Circulation
	The Productivity of the Oceans, their Circulation, and Air-Sea Exchange	GSFC-Atmos/Ocean/Land 4-D Data Animation Penn State U.MSFC-Water Cycle GSFC-Global Water & Energy Cycle BMRC (Australia)-Atmospheric Modeling	•MSFC Hydrology and Hydrodynamics	•EOS-PM -Clouds, Precipitation, and Radiative Balance -Terrestrial Snow & Sea Ice	LAGEOS Laser Geodynamics ATLAS Series Atmos/Solar Effects LITE Series Atmospheric Aerosols
	The Sources and Sinks of Greenhouse Gases, and their Atmospheric Transformations	U. of Washington-Physical Climate over Oceans U. of Texas-Geodynamics JPL-Air-Sea Interaction Woods Hole Ocean Inst-Biogeochemical Flume over Oceans CSIRO (Australia)-Physical & Biological Oceanography	•GSFC Upper Atmosphere, Dynamics, Global Biosphere, Geophysics	-Sea-Surface Temperature and Ocean Productivity •EOS-COLOR -Oceanic Biomass and Productivity	SRL Series Surface Radar Images TOMS Ozone Mapping Sea WiFs/SeaStar Ocean Color TRMM Clouds, Hydrology, Rain

Figure 7. The flow of activities in Mission to Planet Earth from the present to ultimate purposes.

	Changes in Land Use, Land Cover, Primary Productivity, and the Water Cycle	Chilworth Research (U.K.)-Oceans Oregon State U.-Physical & Biological Oceanography Cornell U.-Tectonic/Climatic Dynamics CCRS (Canada)-Northern Hemisphere U. of New Hampshire-Biogeochemical Cycles	●JPL Ocean Circulation, Air/Sea Interaction	●EOS-AERO -Atmospheric Aerosols	**Other U.S. (Data)** POES (NOAA) Global Environment GOES (NOAA) Global Environment DMSP (DoD) Hydrology and Sea Ice Geosat (Dod) Ocean Topography/Sea Ice
	The Role of the Polar Ice Sheets, and Sea Level	GSFC-Biosphere Atmosphere Interactions INPE (Brazil)-Amazonia U. of Cal at Santa Barbara-Snow Hydrology and Chemistry LERTS (France)-Climatic Processes in Arid/Semi-Arid Lands	●EROS Data Center Land Processes Imagery	●EOS-ALT -Ocean Circulation -Ice Sheet Mass Balance	Landsat-6 (EOSAT) Landsat-7 (NASA/DoD) Surface Images Earth Radiation Budget Measurement (DOE)
	The Coupling of Ozone Chemistry with Climate and the Biosphere	U. of Washington-Ocean-Ice-Atmosphere Interactions CCRS (Canada)-Cryospheric Monitoring in Canada GSFC-Middle Atmosphere Chemistry and Dynamics	●Alaska SAR Facility Sea Ice, Polar Processes Imagery	●EOS-CHEM -Atmospheric Chemical Species and their Transformations -Ocean Surface Stress	**International (Data)**Meteor-3 (Russia) Ozone/Radiation Budget ERS-1/2 (ESA) Global Environment JERS-1 (Japan) Sea Ice Characteristics
	The Role of Volcanoes in Climate Change	LaRC-Radiative/Chemical/Dynamical Processes in the Atmosphere U. of Cambridge (UK)-Middle Atmosphere and Thermosphere U. of Hawaii-Volcanism and Climate	●National Snow and Ice Data Center Cryosphere, Snow and Ice Data Products of Level 2 and above		Radarsat (Canada) Sea Ice Characteristics ADEOS (Japan) Sea Surface/Atmosphere

KEY
*Earth Probes Mission
[1]Includes U.S. TOMS Instrument
[2]Launch by NASA
[3]Includes U.S. TOMS and NSCAT (Sea Surface Winds) Instruments
[4]Proposed

RESOURCES MONITORING APPLICATIONS

Although the EOS and other missions have as the principal objectives those associated with atmospheric, biospheric, and hydrospheric scientific matters, the data produced will be continuous, well calibrated, and georeferenced so that it will also be quite useful in monitoring earth resources (see Figure 6). For example, data collected for hydrological science studies, besides providing a better understanding of hydrological processes and how they are involved or affected by climate change and geological change, will provide valuable data for water resources management efforts, such as reservoir design and stormwater-management planning. Observations made to determine ocean color and biomass are of interest and utility to agencies and to private industry involved with utilizing marine resources. Instruments that are capable of observing vegetation dynamics and land-cover change will be applicable to monitoring the extent and condition of food and fiber resources, such as crops, forested areas, and wetlands. Instruments useful for doing geological studies are also applicable to mineral and petroleum explorations. Finally, observations of atmospheric constituents are of direct interest in an environmental sense.

The Mission to Planet Earth instruments (Goddard Space Flight Center 1991) such as Landsat, ASTER, and HIRIS will continue and improve upon the use of high-spatial resolution, multispectral (e.g., 192 narrow bands in the case of HIRIS) observations for a wide suite of resource applications. MODIS and MIMR will allow improved observations over wide areas of land-use change, vegetation condition, snow- and ice-cover change, wetness and water content, coastal water surface temperature, and color useful for fisheries' interests, plus more spectrally rich information useful for locating mineral and petroleum resources. There are no proprietary restrictions on the use of these data, so fundamentally there are no restrictions in the access or use of the data in the EOSDIS.

CHALLENGES

The point to be made here is that residing within the EOSDIS will be large volumes of data that will not only be useful for earth-science research but also for the monitoring and management of earth resources and for making associated resource allocations and economic decisions. The major challenge is to make private industry, state and local agencies, and academia aware of this resource and to provide the mechanisms and other infrastructure to make these data available in a timely fashion and at costs compatible with available or accessible funding. Legislation is now reportedly being considered in the U.S. Congress that may contribute toward this end. Among the technical, as opposed to legislative, infrastructure items involved is the development of archival media that permits the compact and cost-effective storage of large volumes of data for use with microcomputers and workstations so that the data can be widely used and processed to derive information. Electronic access, e.g., networks, and accounting procedures also need to be developed or enhanced to facilitate access to the archival centers and associated archives that are part of EOSDIS (see Figure 7). The further development of geographic information systems (GIS) to combine remotely sensed data, such as that from EOS with that from other sources, is very important in order to facilitate resource management and economic decision-making. A further challenge is to train a body of individuals, not only those in colleges and universities but many who are now in elementary and secondary schools, to have the skills and background to make good use of these data and the tools necessary to analyze and develop the information contained therein.

CONCLUSIONS

The purpose of this paper has been to heighten awareness of the characteristics of the NASA Mission to Planet Earth, including the amount and extent of data that will be forthcoming from this mission. It seems apparent that within the EOSDIS globally acquired data will be of immense value not only for earth-science research, particularly relevant to climate change, but also for earth-resources monitoring and environmental studies of importance in a wide variety of economic prediction and decision-making situations. The challenges include the technical ones of storing and disseminating the data in a timely and cost-effective fashion to a wide variety of users, educating future generations to make optimum use of these data, and providing the legislative framework to allow these challenges to be met and the opportunities for maintaining and improving life on this earth to be realized.

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GIS Systems and Data Management for Global Data Sets in Natural Resources

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Abstract

We are entering a period of very rapid increase in the availability of global natural resources data. This is fortunate because we are also confronted with a long list of global problems that are resource related. GIS technology offers many advantages in dealing with such problems. These rapid changes are driven by developments in computer technology that have occurred at both ends of the spectrum of computing capability—in supercomputers and in personal computers. For example, personal computer users soon will be able to work effectively with many kinds of global databases on systems that cost less than $500. In spite of this progress, there are problems that still need to be overcome. Existing data resources must be captured in or converted to digital form, and all data must be more widely shared. Despite the problems, a dozen or more global databases already exist; and if the public databases are more widely shared, the effect on global problem solving is likely to be profound. Those persons with an understanding of the nature of these changes and their implications need to share their understanding more widely with others.

INTRODUCTION

We are entering a period in the development of GIS and related technologies in which all of the necessary elements are in place for the creation of global GISs for natural resources and related kinds of information. These elements include (1) computer hardware that is inexpensive enough and powerful enough to be both widely available to users and also capable of dealing with very large databases, (2) GIS and database management system (DBMS) software that is capable of dealing with large and complex databases yet is also user-friendly enough to permit a wide range of persons to become GIS users, (3) data communications technologies that are capable of allowing users all over the world to interconnect in a single network, and (4) remote sensing devices that can capture data for the entire world in a few days and do so at resolutions that are useful for natural resources and related problems. These technologies now make it possible to think seriously about what kind of global GISs we would like to have and how they should be put together; indeed, the first such GISs are now in place.

GLOBAL NATURAL RESOURCES PROBLEMS

Naming a variety of natural resources-related problems that are either global in scale or that have global implications is easy: tropical forest removal; energy resources depletion (coal, oil, natural gas, etc.); soil erosion and desertification; management of water resources for drinking, irrigation, and industry; land management for grazing and wildlife; loss of biodiversity; possible global climate change; acid precipitation; and so on. In each of these cases, the possibility of rational decision-making and management of the problem depends on the availability of timely and comprehensive information about natural resources. Fortunately, in many of these cases, the technology is now in place for providing the required information.

PARTICULAR IMPORTANCE OF GIS FOR GLOBAL PROBLEM SOLVING

GIS technology is of particular importance in dealing with global natural resources problems because the base majority of these problems have important spatial and geographic components. They are problems that occur in real space and time at places around the world. Moreover, their spatial aspects are usually important to the solution of the problems. Further, by sharing the same space, many of these problems are interconnected with one another. Thus, spatial or geographic referencing draws these various problems together, and spatial referencing helps to integrate the various kinds of data that are related to the problems.

In addition, the powerful capabilities of computer-based information processing are important to the process of understanding these problems, communicating about them, and, ultimately, devising solution strategies.

COMPUTER HARDWARE FOR GLOBAL GIS DATABASES

The global databases that are needed for dealing with some of these problems are not of overwhelming size, at least in relation to the computer hardware tools now available to us. While supercomputers costing tens of millions of dollars are used for manipulating some kinds of global databases, such as those dealing with global weather, there are other kinds of global databases that can be managed rather effectively by personal computers (PCs).

Indeed, in thinking about solving some kinds of global problems in which the important decision-makers will be officials in Third World countries, the computer standard that ought to be assumed might be an IBM PC or compatible machine with something like a 286 chip. The memory of such a machine can now be augmented with a CD-ROM drive capable of storing more than 800 megabytes of data on a single CD. By changing disks, such a computer system could deal rather effectively with a database consisting of many gigabytes. (As will be seen below, the first publicly available digital GIS database for the world at a scale of 1:1,000,000 contains something over seven gigabytes of data and is designed for use in a PC environment.) Moreover, CD-ROM storage is quite inexpensive. It is also stable, easy to ship from place to place, and it avoids the problems often connected with network communications in many parts of the world.

Thus, while for some applications supercomputers or mainframe machines or powerful workstations are important, there are many applications of global natural resources GIS databases in which quite inexpensive machines can be useful. This means that a very wide variety of user organizations and even economically weak governments are now in a position to begin taking a broad view of the natural resources problems that face them.

The time is not far off when complete computer hardware/software systems for dealing with global natural resources problems will cost less than $500. When this occurs, it may lead to quite a different approach to global problem solving.

Similarly, the time is not far off when the capabilities of present supercomputers will be available in desktop machines that will also store gigabytes of data quite compactly, which is also likely to revolutionize our approach to global problem solving.

A final revolution now under way is the revolution in data communications. In various places in the developed world, fiber-optic communications networks capable of transmitting hundreds of gigabytes of data per second over long distances are being put in place. When such a network links the countries of the world, global GIS databases can be centrally maintained and yet widely shared. This process of sharing may even beget international cooperation in solving global natural resources problems.

PROBLEMS WITH GLOBAL SHARING OF GIS DATA

Despite these encouraging circumstances, there are still numerous problems that must be overcome if true global sharing of natural resources GIS information is to be achieved.

At the present time, much of the data needed for approaching global problems is not in a form that can be combined with other data into a single, coherent database. Numerous hurdles must be overcome. In many cases, the required baseline data, which would permit comparisons between present conditions and those of the past, are simply not available or they may be available only in nondigital forms or they may be widely scattered.

In many cases, the data are in the form of paper maps. An effective means of rapidly, inexpensively, and accurately capturing such data is still needed. Although scanning has come a long way, it still does not fully meet the needs in this area. Nevertheless, there is hope that within the next decade or so, with wider use of expert systems technology, the remaining hurdles to effective scanning will be overcome.

Where data are in digital form, they are often in forms that are incompatible with one another. This is often more than a data conversion problem: The classification systems (for soils, vegetation, etc.) may be incompatible with one another; the scales at which the data were gathered may make them mutually incompatible; other kinds of problems with bringing the data together may be present. In many cases, these problems can be overcome by labor-intensive manual methods of integration and standardization. Unfortunately, such methods are not widely understood or practiced. Much work needs to be done in this area, and the costs are likely to be considerable.

In some cases, all that can be done is to attempt to establish data standards for future data-gathering efforts in order to ensure mutual compatibility. A large number of organizations are working now to establish just such standards, and new international standards for GIS data are being tested at the present time. Once accepted, it will be necessary to work to obtain wide compliance with such standards.

Even where data exist in a suitable form, they are often not effectively shared. There may be economic, business, political, or bureaucratic reasons for this problem. Arrangements that foster much wider sharing of available global natural resources data are needed. Where successful examples of sharing are found, they should be widely copied. The end of the cold war offers a unique opportunity, unavailable in seventy years, for global data sharing: We ought to take advantage of this opportunity.

BEGINNINGS OF GLOBAL NATURAL RESOURCES GIS DATABASES

Ten public global databases of various kinds are maintained by about an equal number of international organizations. The latter include United Nations organizations as well as international scientific organizations. Most of these databases were created within the last decade or so. Most deal with natural resources in one way or another. They include data on such important natural resources as tropical rain forests and rare, threatened, or endangered species; they are designed to deal with such important problems as desertification and global climate change; they go by such now familiar names as GRID and GEMS.

While they are important, these databases are but the first of the global GIS databases and are not necessarily representative of what global databases will be like in the future or how such databases will be created, maintained, and used. Many have been compiled at considerable cost over many years through the efforts of often widely scattered groups of devoted workers. The negotiations required to produce the databases have often been tedious and time-consuming. Each such database is a pioneering effort in its own way; but it may be that in the future the creation of such global databases will be accomplished more rapidly and efficiently, both because of what has been learned through these pioneering efforts and because of rapid improvements in technology over the last two decades.

Very recently, for example, the U.S. Defense Mapping Agency (DMA) has converted more than 270 of its 1:1,000,000 aerial navigation charts to digital cartographic data in the form of a single Digital Chart of the World (DCW). The database is on four CD-ROMs that contain a total of about seven gigabytes of data, and these digital data conform to a single, well-defined set of standards. They probably represent the largest-scale publicly available digital GIS database ever assembled. The cost of the data on the original charts has not been calculated, but the cost of the conversion process alone approached 10 million dollars. Yet the data on the set of four CD-ROMs can be purchased by anyone for a few hundred dollars. It now seems likely that the DCW will become the de facto basemap for a wide range of new global geographically referenced databases. This project may be the prototype for other global database efforts in the near future, especially as various kinds of intelligence information gathered over the last forty years is declassified and released by the United States, Russia, and other nations.

Recent advancements in data collection, remote sensing, image processing, and other technical areas are likely to make the creation of global natural resources databases somewhat easier. For example, since the end of the cold war, the resolution of some kinds of unclassified satellite remote sensing data, available to the general public, is now about 2 meters. This means that satellite remote sensing of some kinds of complete global natural resources (forests, waters, etc.) is now within reach of anyone who can afford the price of the imagery. Rather than making use of ground survey methods or aerial remote sensing globe circling, repetitive satellite remote sensing can be used instead. This is an extraordinary step forward.

In the next decade, a revolution in ground-based sensing devices will likely occur, providing a wide range of inexpensive, highly accurate ground measurements of variables such as soil acidity, ambient gases, etc., which cannot be obtained by remote sensing. Combined with advances in remote sensing, this development offers extraordinary promise for global natural resources databases.

WIDER PARTICIPATION IN GLOBAL NATURAL RESOURCES PROBLEM SOLVING

While these developments offer great promise for specialists who deal with global natural resources problems, other technical developments promise a revolution in how such problems are approached.

Developments in GIS technology, especially in the user interface to GISs, now make it possible for untrained, nontechnical users to examine GIS data in much the same way that they would look up information in a printed reference work. When such interfaces are coupled with global natural resources databases, the effect will be to provide average citizens with the possibility of gaining direct insight into global problems without the need for technicians, scientists, and others as intermediates or interpreters. This will likely produce a revolution in the way we approach these problems. For example, it may lead to true grassroots problem solving and will likely produce new perspectives on the problems themselves and new suggestions for solutions. It will certainly affect the way in which various government and organizational decision-makers approach global problems.

As with the technical developments in computer and communications hardware, the developments in user-friendly GIS software are likely to continue and perhaps even speed up. We are only just beginning to see what the implications of these changes are going to be.

ADDITIONAL NEEDS

Despite all of these promising advances, it is likely that some additional kinds of global data will be required before we can be confident that we have the right information to move forward with problem solving.

Computer capabilities and data-gathering capabilities may make it possible to think about global time-series data that go beyond merely a series of satellite images. Very little is known about how most aspects of the global environment change over time. Perhaps in the next decade or so we can change that. Similarly, data about a much wider range of variables is needed. To a considerable degree, we are constrained now to think about and model with those data that it is convenient to gather. Many kinds of data would be useful to have, but we cannot obtain them because of a lack of appropriate sensors, because of the costs of gathering the data, and for other reasons. That may change also. If so, in the future we may be able to create true multidimensional global databases of the kind required for global problem solving.

Much of the data that has been gathered over recent decades is in danger of being lost forever because it is not properly recorded and stored. While the costs of preserving these data are not small, the costs of losing them are incalculable. Those concerned with global natural resources data need to make much greater efforts to preserve this important legacy for future workers.

NEW USERS OF GLOBAL NATURAL RESOURCES INFORMATION

At the present time, the people concerned about global natural resources databases belong to a very limited group of specialists; but as the coming revolutionary changes in processing these data occur, the number of interested people will grow rapidly. With reasonable costs for the data, easy to use GIS software, and wide availability, global natural resources data will be used not just by scientists, governments, and a few nongovernmental organizations but by businesses, educators, and the public. As a result, more and more people will adopt a global perspective in thinking about their own work and their personal decisions. Newspapers, television, and other media can be expected to take a more global view in describing and explaining the daily news. The school children of the future may become as accustomed to thinking in global terms as they are now accustomed to thinking in terms of their own country, their own city, and their own neighborhood. The effect of such changes is likely to be profound.

CHALLENGES

All of these developments present those of us who work with these data and these technologies with many kinds of personal and professional challenges. We must keep abreast of the developments technically; we must understand their implications; and we must foster change where it seems useful and wise to do so. More than this, we must take the time to explain to others, outside our narrow fields, the significance of the information revolution that we can see so clearly. We must, in particular, help decision-makers as well as the public understand the implications of the coming wider availability of global natural resources data.

An Historical Analysis of GIS

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Abstract

This paper presents an historical analysis of the GIS industry, focusing on examples from the past twenty years, and includes an introduction on the origins of GIS. Specific topics discussed are an analysis of raster and vector processing capabilities, the integration of data base management systems (DBMS) into a GIS, digital orthophoto mapping, and raster/vector integration. The future of GIS will present a need for better user education as the capabilities of the industry grow, as data sources multiply, and as an increased number of platforms become available. The industry will face other challenges, such as the need for data compression, parallel processing, and a greater need for softcopy photogrammetry. There is definitely more acceptance by the user community of the use of raster processing than in years past, and the appreciation of the value of this technology has broadened as well. GIS is now an essential tool in resource management, forestry, global monitoring, transportation planning, mineral exploration, state and local government, and in a host of other areas.

INTRODUCTION

The advantages of geographic information systems (GIS) and image-processing (IP) techniques include statistical and spatial modeling, processing for better data sources, improved information management, the ability to perform enhanced productivity and integration, and the idea of cost-sharing capabilities between various users within an organization.

Over the past two decades, there have been numerous technological developments, including more efficient and lower cost computers, workstations with fully integrated networks, higher resolution displays approaching 2 k x 2 k, less expensive color hard copy and black and white printers, and film recording devices. There has also been the emergence of extremely large disk storage capabilities, open hardware architectures, and operating systems specifically moving toward open operating systems such as UNIX and DOS.

GIS/IP PROCESS

To conduct a project effectively today, a user needs a database, tools, and tested methodologies in place. Almost any project requires construction materials, such as raster data, vector data, and tabular data. Raster data include satellite imagery (e.g., Landsat, SPOT), scanned aerial photographs, and other types of imagery, such as digital elevation models (DEMs) and digital cartography (e.g., thematic layers of land cover, slope, aspect). Vector data are composed of points, lines, or polygons and can include such features as political boundaries, railroads, and rivers in formats such as Digital Line Graph (DLG), TIGER/Line, AutoCAD, ARC/INFO. Tabular data can include attribute information, geographic coordinates, and demographics.

Bringing all of these data types together requires computer hardware, displays, peripheral devices (such as scanners, digitizers, printers, and tape drives), and the required software to link these components. Other tools for complete support include hardware and software maintenance updates, telephone hotlines, etc. Once a system is acquired and set up, the end user must be trained to use it. Training and other professional services are in high demand. As the number of hardware and software vendors escalates, quality service programs, such as training and software support, become major selling points. This becomes critically important as GIS technology is targeted to a wider audience of "generalist" users.

TECHNOLOGICAL DEVELOPMENTS

Different "waves" or "cycles" have existed within the computer industry over the past twenty years. This started with the boom in mainframe computers, which then led into minicomputers, personal computers, and finally into open workstation systems. The cost of computing power has come down dramatically over the past couple of years, going from $1,400 per MIP in 1989 to breaking the $200 barrier in 1991. The power range has gone from five-plus MIPS in 1989, with performances in the seventy-plus MIPS range in 1991, and clearly going into the three-digit range in 1992.

There has also been a tremendous proliferation in terms of the installed base of GIS systems over the past several years. GIS systems are now on virtually every continent and are sold in greater quantities to more and more organizations. There has been an evolution in the type of users of these systems from the very technical users to what some would call the more "casual users." This trend started over the past several years and will probably grow rapidly in the upcoming years due to new developments within the industry. In 1988 the entire GIS market of services, hardware, and software was worth $550 million. By 1993 the expected value of this market is estimated to be $2.1 billion, an increase of almost fourfold.

One might wish to explore the reasons why GIS and digital remote sensing techniques are taking hold in so many diverse markets. One reason is that the population of our planet is growing at a phenomenal rate. The earth's growing population presents the distinct likelihood of a shortage of natural resources as people in different countries look for improved lifestyles and desire many of the same resources that are currently used in the United States. As the planet becomes more populated, there will be a greater need for governments and corporations to evaluate and to analyze the resources that they control; and in turn there will be a greater demand by these users for cost-efficient and friendly technologies to analyze this information.

DATA ACQUISITION

One of the many challenges facing the GIS industry is the ability to collect information in a timely and cost-effective manner. According to surveys by Daratech Inc., (Cambridge, Massachusetts), 65 to 74 percent of an organization's GIS dollars will be spent on data acquisition. If this costly and tedious process could be streamlined, it could create vast dollar savings and great financial recovery for any organization's budget. In the 1970s and probably into the 1980s, organizations spent large sums of money on hardware and software and had precious little time for actually analyzing the data and determining the implications of that analysis on the particular project at hand. However, in the 1990s as hardware and software costs drop and as organizational expertise and ease of data collection become enhanced, data and analysis will become the driving force.

Many organizations are keeping data costs low by using their data efficiently. To update a vector database quickly and accurately, users can display vector data over raster satellite data or aerial photographs. Through heads-up digitizing, new information can be entered into the database. This saves the time-consuming and expensive task of field checking information that is already outdated.

Another technique for reducing data costs involves combining data from different satellites. By performing a spectral merge of two data sets, users can derive a data set that provides new information about the study area. This data set could be considered a data fusion or the product of an analysis capability. For instance 30-meter Landsat Thematic Mapper (TM) multispectral data can be merged with 10-meter SPOT panchromatic data to produce a new file that contains the spectral diversity of the Landsat data and the cultural detail of the SPOT data. These techniques can also be applied to other data types, such as the Russian satellite, the Japanese MOS, the European ERS-1, and the Canadian Radarsat.

EARLY TWENTIETH-CENTURY GIS

GIS has much of its origin in the science of landscape architecture. Frederick Law Olmsted has long been considered the father of the landscape architectural profession. In the late nineteenth century, the landscape architectural firm of Olmsted & Associates was well known for its significant work in the design of Yosemite National Park, New York Central Park, and the Cotton States Exhibition, which later became Piedmont Park, held in Atlanta, Georgia, in 1894. In 1901 Olmsted founded the first Department of Landscape Architecture in the United States at Harvard University. It is no coincidence that the GIS industry got its start from research projects conducted in the 1960s at Harvard's Department of Landscape Architecture and at the Laboratory of Computer Graphics and Spatial Analysis.

Before going into the last twenty years of what might be considered modern GIS, it might be useful to reflect a minute on an article entitled "Hand-

Drawn Overlays: Their History and Prospective Uses" by Carl Steinitz, Paul Parker, and Lawrie Jordan, III. This article was published in *Landscape Architecture Quarterly* in July 1976. It described many of the methods used by early pioneers in this profession. For example:

1. Overlay interpretation of land data by Warren Manning in 1912 in Billerica, Massachusetts (first reported in *Landscape Architecture Quarterly* in 1913)

2. Time-series change analysis in Dusseldorf, Germany, in 1912

3. Excessibility isolines and their regional planning scheme for Doncaster, England, by Abercrombie and Johnson in 1922

The article goes on to describe studies in New York in 1923 to map economic and demographic overlays, base map underlays used in 1929 in New York, Lunding County work in the early 1940s, and many other examples of town planning in England, indicating that although the GIS technology was not present there were many examples of analytical land planning and analysis dating as early as the late nineteenth century in England.

GIS ANALYSIS: THE LAST TWENTY YEARS

1970s

During the early 1970s, there were many examples of GIS development using manual techniques to place various data sources into a digital environment. Analysts could use a mylar-drawn grid to interpret soils information or to capture data from a USGS quadrangle map, an aerial photo, or another source to produce a black and white, or gray-scale, computer generated map. Manual overlays of slope analysis for highway corridors were hand-drawn from standard data sets. Rather sophisticated analytical techniques were accomplished manually in the absence of technology to augment those analyses.

Over the next couple of years, entering the mid 1970s, there were examples of users attempting to mosaic and interpret large numbers of aerial photographs to provide a land-cover analysis of a large region. Often by mosaicking this information, the absence of some data would create voids in the data set. At this time, we also witnessed digital display systems, rather primitive by today's standards but nonetheless able to display and perform rudimentary analysis capabilities.

As GIS progressed into 1976 and 1977, some of the digital processing systems were able to display data. These systems allowed the user to interactively pick out points that closed a polygon on screen and then statistically read the information for each band of data and draw histograms. This process allowed the user to evaluate the homogeneity of the various training samples, to analyze the satellite data with high-altitude aerial photography, and to create digital cartographic maps of different vegetation themes. During this period, users were beginning to come together at large conferences to discuss GIS and remote sensing capabilities.

In 1978 and 1979, the ERDAS 400 geoprocessing system was introduced. This revolutionary system was brought out on the market at a cost of $50,000 for hardware and software. The system provided the user with 48 kb of memory; an 8-inch, single-sided, single-density, one-quarter mb floppy disk; two disk drives, A and B; a floating point processor; a display of 256 x 256 x 16 bits of data; a printer; and a display terminal. The software integrated basic image processing and raster GIS functionality in a menu-driven, user-friendly environment, allowing novice users to interact with the system in a way that was impossible before.

1980s

From 1980 to 1982, projects such as the mapping of New York's Adirondack Park were begun. In this project, a state jurisdiction of approximately 9,200 square miles was mapped into a GIS, using digital image-processing techniques. In other examples from this time, USGS quadrangles within an area would be integrated into a GIS, where change-detection could be performed on the digital data and various models run to perform an analysis.

In 1982 the Alaska Department of Natural Resources Geologic and Geophysical Survey Project defined several GIS improvements required for increased GIS use. These were (1) the need for floating point data to facilitate the integration of image processing with GIS systems; (2) NURE (National Uranium Resource Evaluation) data, which are published at a variety of scales. Statistical packages for variants in scaling demonstrated the need for the geochemical and geophysical data to be merged. This seems to be possible through use of a common remote sensing database; and (3) a need for techniques dealing with surfacing and kriging to be integrated into the planning process.

In 1982 the U.S. government sponsored private firms in an effort to map large areas for proposed high-level nuclear waste disposal sites. The neighborhood analysis functions of raster GIS systems provided the ability to develop models that would output maps showing only those areas that fit all of the conditions required for safe nuclear waste disposal. This was also an important step in the development of GIS technology because software packages were now being designed to perform very detailed analyses on very large areas. A high-level waste disposal project in western Texas included the mapping of entire counties that were approximately 30 by 50 miles as well as the ability to window specific areas. This provided for detailed mapping so that specific land parcels could be analyzed to determine the location of farms and historical and archaeological sites.

In 1983 the U.S. Forest Service mapped eleven counties within South Carolina to locate prime timberlands. Prime timberlands were specifically divided into two categories: (1) lands capable of producing at least 120 cubic feet of wood fiber per acre per year and (2) lands able to produce 85-120 cubic feet of wood fiber per acre per year.

For this project, the U.S. Forest Service input MIADS digital data from the USDA Soil Conservation Service as an example of soil productivity and used Landsat Multispectral (MSS) data for gathering land-cover information. This project was successfully completed by taking some ninety-five different MIADS soil conditions and recoding those into approximately five different categories of productivity. The soils data were then merged with the Landsat data, which were mapped into categories of coniferous vegetation, deciduous vegetation, areas of no vegetation, urban areas, nonforested areas, and water bodies. The sites of highest value were considered to be areas with highly productive soils that had no trees currently growing and could be planted immediately to yield a good timber product in the next twenty to thirty years.

Starting in 1983, the Army Corps of Engineers conducted research on the Tennessee/Tombigby Waterway to evaluate GIS techniques for industrial site location studies and to determine ways in which training and community involvement could be brought to the users. This was done in an innovative fashion by installing GIS technology in a mobile trailer for training and technology transfer within a four-state region.

Around 1984 and 1985, as GIS analytical capabilities were improving so were the capabilities of the hardware, with the emergence of the IBM PC/XT and the initial version of the DOS environment. Also seen was the proliferation of low-cost image displays enabling the user to have a single-vendor solution by adding a single 24-bit true-color display with various monitors, tape drives, digitizing tablets, printers, film recorders, and scanners.

During the mid 1980s, examples emerged of various image algebra functions as well as the ability to perform three-dimensional representations of the landscape. The three-dimensional capabilities were performed by merging satellite data with terrain data, warping the data sets to each other, and analyzing the landscape on the X, Y, and Z axes.

From 1986 to 1987, sophisticated techniques for image scanning were used and the initial UNIX standards through the Sun-3 Workstation emerged. The added power of the workstation environment allowed the addition of new capabilities to ERDAS Version 7.3 software:

1. *Annotation* allows the annotation of images with text, legends, borders, and graphics.

2. *Topography* allows users to create elevation contours from paper maps, to show shaded relief, and to compute aspect and slope.

3. *Three-Dimensional Analysis* allows users to create 3-D perspective views from satellite imagery.

4. *Image Algebra* allows images to be added, ratioed, transformed algebraically, trigonometrically, logarithmically, and exponentially. Image algebra allows users to perform areas-of-interest analysis by using a boundary file to define the area.

Raster/Vector Integration

Raster and vector integration techniques have allowed the user to have the benefits of both types of data sets in one GIS. Digital images like satellite data were once considered "dumb," with no real value. However, new interfaces make it possible to bring together raster satellite images and scanned aerial photography with vector GIS systems. For example, between 1989 and 1991 the Suwannee River Water Management District (SRWMD) in Florida demonstrated the power of raster/vector integration when the use of satellite imagery was introduced into the existing vector GIS. SRWMD needed up-to-date and detailed land-cover information to protect the 7,600 square miles of Florida's rivers and lakes from pollution and to ensure proper management. The integration of raster satellite imagery into the SRWMD GIS was one of the largest raster/vector conversion projects ever completed. In addition to being easily updated to provide current information, the raster/vector method proved to be cost-effective and less time-intensive; and it provided the degree of detail needed for SRWMD purposes.

In 1988 and 1989, ERDAS introduced several new GIS functions including GIS modeling (GISMO) and the SEED statistical classifier. GISMO is a tool to create information maps and analytical models from raster data layers. GISMO modeling techniques can be used to answer complex questions, using information about the land surface. For example, a GIS model may be used to compute the suitability of areas for urban development, to locate critical habitat types, to rank groundwater protection areas, or to calculate the economic and environmental impact of a major industrial plant on a large area. The advantage to modeling is that it allows users to change the input parameters and then create and observe an updated model on screen almost instantly.

With the SEED statistical classifier, users can pick a single pixel that is representative of the type of area to be classified, and other pixels with similar characteristics will "grow" and be automatically highlighted on the display. The resulting training samples are precise representations for the selected categories. This technique can be extremely useful for updating vector coverages and for allowing the user to quickly gain spatial knowledge of the various categories that are being mapped or evaluated.

The ERDAS Multivariate Image Analysis (MIA) module enabled users to analyze images without the use of ground-truth information or in applications such as mineral exploration where an iterative process is necessary to enhance features that are not obvious in the original imagery. Scatterplots of any band combinations are produced on the screen, showing the highest discrimination potential. The user draws boundaries around pixel values of interest, and the corresponding pixels are highlighted on the original image. This technique is also useful for determining boundary conditions such as wetlands mapping.

About this time, Global Positioning Systems (GPS) also emerged. The United States Defense Department invested $10 billion to launch a series of satellites for navigation. These satellites offer precise global navigation for land, sea, and air applications. From inexpensive receivers, processors, antennae, and hand-held devices, users can tap into the GPS satellite information (at no charge) and compute precise position, velocity, and time. The latest technology developed by Trimble Navigation, Ltd., allows both geographic coordinates and attribute information to be read into ERDAS directly.

This is extremely important information when dealing with a study area that has very old base maps or if the area has been modified. Without accurate ground control points, it is difficult to get accurate rectification results. With GPS technology, users can go to a study area and determine ground control points effectively and accurately. A second valuable use of GPS is for creating DEMs and orthophotos since the technology provides X, Y, and Z elevation values. The third valuable asset of GPS is in land-cover classification. Users can better define training samples for accuracy assessment in field verification.

1990s

In 1990 and 1991, softcopy photogrammetry gave GIS users the ability to create DEMs and digital orthophotos. Software such as the ERDAS Digital Ortho module allows users to do the following:

1. Create Digital Elevation Models (DEMs)
2. Create digital orthophotos from DEMs
3. Use DEMs with other software modules (3D, Topographic) and
4. Create 3D-perspective views, slope, aspect, contour, and shaded relief maps

Digital orthophotos are terrain-corrected images that can be used as precision base maps for GIS databases. The introduction of DEMs into a GIS adds a new dimension to many analyses whether the project involves facility siting, the delineation of wildlife habitats, or the probable location of minerals and deposits.

The next generation of GIS systems will conform to both the "casual" and the "expert" GIS user, presenting a user interface that is friendly and easy to interact with as well as technologically sophisticated, providing advanced analytical features.

The next generation of GIS and raster image-processing software will include a point-and-click graphical user interface with buttons, icons, scroll bars, and other dynamic visual aids, such as interactive histograms, color tables, function graphics, and pull-down menus. It will also include context-sensitive hypertext on-line help, editable batch-processing scripts, session histories, and a tiled file structure enabling users to roam the disk. The new GIS software will operate under a standard windowing environment, such as the X Windows OSF/Motif environment, giving users unlimited windowing ability for viewing the same area in different ways. Systems such as this give analysts the power to visualize solutions.

CONCLUSION

GIS industry has come a long way since its beginnings in landscape architecture almost 100 years ago, and the growth rate over the last twenty years has exceeded even the most optimistic expectations. The next twenty years will see the broadening of the GIS user base to include diverse disciplines, using the technology for a myriad of applications. To meet the challenges of this dynamic industry, vendors must listen to users, tailor packages for specific applications, provide powerful and user-friendly software, and offer professional services such as training. Users must continue to demand products that are well tested, well designed, and able to solve the problems they face today, as well as those they will face tomorrow. As in any technological field, there will continue to be hardware advances that necessitate equipment upgrades, but these new systems must be compatible with earlier models. GIS projects can take years to complete; therefore, continuity of data, software, and hardware must be maintained. The key to continued success in the GIS marketplace is communication and vision—the ability of users and vendors to understand the position of the other and the vision to make the decisions that will benefit the users of the future.

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The Global Resource Information Database

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Abstract

The United Nations Environment Programme (UNEP) is responsible for initiating and stimulating environmental action and awareness at all levels of society worldwide and for coordinating the environmental work of all United Nations organizations and agencies.

Within this framework, UNEP has established the Global Resource Information Database (GRID) to provide the world community with access to timely, usable environmental data and access to the geographic information system, satellite image processing, and telecommunication technology necessary for each data recipient to make the best use of these data and for global science applications, wise resource management, and sustainable development planning. Through GRID, UNEP will address environmental issues at global, regional, and national levels to bridge the gap between scientific understanding of earth processes and sound management of the environment.

The long-term objectives of the GRID activity are to ensure that (1) all pertinent global and regional environmental data are available through the GRID network to a range of users from students to scientists to politicians; (2) all United Nations specialized agencies and most major intergovernmental organizations will have access to modern technology and the opportunity to provide the necessary information-management support within their own organizations for the description, understanding, and solution of environment-related problems; (3) all countries will have access to GRID data and technology, with most having functioning GRID-compatible monitoring and assessment centers for national environmental assessment and management support.

The GRID is designed to become a network of cooperating centers in various regions of the world. At present there are GRID centers in Geneva, Switzerland; Warsaw, Poland; Arendal, Norway; Nairobi, Kenya; Bangkok, Thailand; Kathmandu, Nepal; Tsukuba, Japan; and Sioux Falls, United States. Soon there will be GRID centers in Brazil, Russia, Germany, the Caribbean, and the South Pacific. Each of these centers has specific functions within the network. Certain centers deal with sectorial or discipline-specific information; other centers have responsibility for specific geographic areas; still others deal with new technology and general data services.

INTRODUCTION

The United Nations Environment Programme (UNEP) is responsible for initiating and catalyzing environmental action and awareness at all levels of society worldwide and for coordinating the environmental work of all United Nations (UN) organizations and agencies. UNEP has the mandate to marshal, coordinate, bring to bear, catalyze, and occasionally underwrite science in support of the Environment Programme. Thus, within the identified concentration areas for UNEP activities—climate change, biological diversity (including deforestation), fresh water resources (particularly shared watersheds), land degradation, man's impact on oceans and coastal areas, and hazardous wastes—UNEP is concerned with providing the necessary information for assessments of the state of the environment, for structuring environmental plans of action, and for giving teeth to the protocols of international conventions. Within this framework, UNEP has established the Global Resource Information Database (GRID) to provide the world community with access to timely, usable environmental data and with the necessary geographic information system

(GIS), image processing, and telecommunication technology to make best use of such information for global science applications, wise resource management, and sustainable development planning.

GRID's main tasks are data collection and dissemination. In collaboration with UN organizations, national governments, environmental groups, and scientific bodies, GRID also supports scientific research, training, and technology transfer. GRID uses images, maps, and tables derived from data acquired by satellite sensors, aerial reconnaissance, and ground surveillance. GRID processes and stores data in a way that makes them easily accessible and comparable, using several complementary computer hardware and GIS and image-processing software systems.

BACKGROUND

In 1983 the management of Global Environment Monitoring System Program Activity Center (GEMS/PAC) of UNEP headquarters in Nairobi, Kenya, requested assistance from NASA to develop and implement a spatial data-management system for recording, processing, and distributing environmental data and information on a global scale. A user study had been completed by a UNEP chartered expert group. NASA personnel conducted a review of the data types held by several United Nations and intergovernmental organizations. Included in the review were the United Nations Educational, Scientific, and Cultural Organization (UNESCO), Food and Agricultural Organization (FAO), UNEP, International Union for the Conservation of Nature (IUCN), United Nations Disaster Relief Organization (UNDRO), and elements of the European Economic Commission (EEC). Based on the results of the data review, a system was designed; and a prototype system was developed. In late 1984, the Executive Director of UNEP reviewed the prototype system and approved the pilot phase of the GRID activities. He also requested continued NASA assistance to provide equipment and technical personnel to support the pilot phase.

In September 1985, the first of the NASA-built prototype systems was placed in service in Geneva, Switzerland; and a few months later, a second prototype was placed in service in Nairobi, Kenya. The NASA systems were raster based, employing a NASA software known as ELAS. The Prime Computer Company also contributed computers to both centers, and the Environmental Systems Research Institute (ESRI) donated the necessary ARC/INFO software to accommodate the vector-based processing needs.

The initial plan for GRID was to establish a rather large operating unit in Geneva to serve as the global distribution center and archive, with a small unit at the UNEP headquarters in Nairobi to serve the countries of Africa. The first three years were devoted to the development of policies, procedures, and processing techniques, to the initial organization of data in the archive, and to developing a training program for users. By the end of the pilot phase (1988), it had become obvious that the plan for one central distribution and user-training center and archive would have to give way to a distributed network; and a third center was opened in Bangkok, Thailand, in 1988 to serve the Asia and Pacific region. Other centers were added to the network to cover specific countries or geographic regions and still others to provide specific disciplinary expertise or sectorial data or information. At the present, there are eight active GRID centers with four others scheduled to begin operation during 1992. Thus, the mechanism for developing a distributed global network of environmental databases is well into the implementation phase.

It is appropriate here to mention the supporters of the GRID system over the past seven years. They are

1. The United States Government, NASA, and USGS/EDC-GRID Center operations, plus computer hardware and software and technical and scientific personnel to support numerous GRID Center Operations around the world
2. Prime Computer Co. (computer hardware and software)
3. Concurrent Computer Co. (computer hardware and software)
4. IBM Computer Corp. (computer hardware and software)
5. SUN Microsystems Inc. (computer hardware and software)
6. ESRI (GIS software systems)
7. ERDAS (image-processing software systems)
8. Government of Switzerland (funds for training programs)
9. Canton of Geneva (facilities and scientific personnel)
10. Government of Australia (image-processing system hardware and software)

11. Government of Norway (GRID Center operations)

12. Government of Japan (GRID Center operations)

13. ICIMOD (GRID Center operations)

14. Government of Poland (GRID Center operations)

15. Asian Institute of Technology (GRID Center operations)

16. UNITAR (training program development and implementation)

17. Numerous institutions and individuals for specialized data, specialized software, training support, and advice

THE PRESENT NETWORK

The present network was shaped by many forces and events. There are three institutional requirements necessary for the success of any global environmental information network. The first and foremost requirement is the cooperation among scientists and resource managers that promotes the sharing of data and information, both local and regional, that can add up to global coverage. This cooperation is by far the most difficult part to achieve because it involves long-term efforts by both diplomats and scientists. During the first three years of the GRID activities, this element received the primary attention of the project management. Almost every existing global-regional data set was acquired by GRID and processed to common format and projection. By the end of the pilot project in 1988, the GRID database was beginning to gain significance in the data and information world.

The second most important requirement must be the organizational mechanism to carry out the mission of data acquisition and distribution and user training. In 1988 at the end of the pilot project, UNEP management made a decision to abandon the one-central-center concept for GRID and to proceed to develop a distributed network of GRID centers around the globe.

Many factors entered into this change in plans, but the primary factor was pressure from the developing countries through the UNEP Governing Council to bring GRID technology closer to their countries by establishing GRID centers to serve each region of the world. In this time frame, UNEP's total annual budget was less than 30 million dollars; therefore, a very austere plan to establish regional centers was developed.

The Asia Pacific Center was opened in late 1988 on a shoestring budget, which allowed for minimal staffing and little facility and equipment budget. The center was opened using shared facilities at the Asian Institute of Technology (AIT) in Bangkok, Thailand, and instantly came face-to-face with the reality that it was to serve 56 percent of the world's population, more than 80 percent of whom were living in developing countries with very few resources to devote to environmental concerns. It was immediately obvious that other mechanisms would have to be brought to bear in the Asian region. Contacts were made with the International Center for Integrated Mountain Development (ICIMOD) in Kathmandu, Nepal; the South Pacific Regional Environment Program (SPREP); the Indian Ocean Commission; and the governments of Japan and Australia to support the GRID effort through subregional and national organizations. In 1990 an agreement was signed with ICIMOD in which UNEP/GRID would provide training for fifteen ICIMOD scientists and technical personnel plus assistance in hardware/software system design. ICIMOD would in return provide training and assistance to its eight member countries plus data capture and data dissemination for the entire Hindu-Kush Himalaya mountain range. ICIMOD received a grant from the Asian Development Bank in 1990 for both equipment and training courses and became a cooperating GRID Center in 1991.

A similar initiative was started with SPREP in 1990 for the twenty-two island countries embraced by the South Pacific Commission. Plans call for the opening of a GRID/SPREP center in 1992. The center would be funded by both UNEP and the Asian Development Bank and would be responsible for data capture, data dissemination, and training in the South Pacific.[1] Also, in 1990 contacts were made with the government of Japan requesting its assistance with the GRID mission. The Japanese responded in 1991 by opening the GRID/TSUKUBA at the National Institute for Environmental Studies, an element of the Japanese Environment Agency. This center, funded entirely by Japan, provides access to Japanese satellite data, socioeconomic data in spatial format, super-computer processing, and scientific and technical expertise for the GRID systems in general and neighboring developing countries in particular. Other subregional organizations in Asia are also candidates for GRID cooperation. These include the Mekong Secretariat, Indian Ocean-Marine Action Plan, and the ASEAN organization.

[1] In 1992 a GRID cooperating center opened in Western Samoa as part of the South Pacific Regional Environment Program. *Ed.*

In Europe, the network began with GRID/Geneva, which served all of Europe until 1989 when the government of Norway provided funding to open and operate a GRID center in Arendal, Norway. The Arendal Center serves the country of Norway and provides specialized data and information for the Arctic Region. The center also provides assistance to the developing countries through special projects. The third GRID center in Europe was opened in 1991 in Warsaw, Poland. This center, known as GRID/Warsaw, is operated by the government of Poland with assistance from Norway, serving the country of Poland and providing expertise to assist in regional problems in Eastern Europe. Discussions are under way with the Federal Republic of Germany (FRG) and also with Russia, both of which plan to open GRID centers sometime in 1992 or early 1993. There is also talk of a GRID center for the countries of the Baltic Basin.

In Africa the GRID Center in Nairobi remains the primary GRID activity. Through active participation in regional and national projects and through training programs, small centers at the national and intergovernmental levels are being established. National capabilities now exist in Kenya, Senegal, Ghana, Leshoto, and Uganda; and others are under development. The trend in Africa appears to be more toward national capabilities, perhaps due to the lack of strong subregional organizations.

In Latin America, progress has been very slow due primarily to the lack of strong regional or subregional ties among the countries and possibly due to lack of strong UNEP ties in the region. The UNEP regional office is located in Mexico City, which is certainly not a central location, and activities seem to be stronger in Central America and in the Caribbean. In 1990 a GRID center was opened at the Mexico City location for a short time; however, it was closed within two months due to a funding restriction imposed by the UNEP Governing Council. The restriction was imposed on all UNEP funds and was unrelated to GRID, and GRID/Mexico City was only one of the victims. In late 1991, contacts were made to the government of Brazil; and the Brazilian Space Agency, Instituto de Pesquisas Espaciais (INPE), has made a positive response. The agreement to establish GRID/Sao Jose dos Campos at INPE Headquarters will be signed at UNEP's World Environment Day celebration in Rio de Janeiro on June 6, 1992.[2] The center will be operated with funds provided by Brazil and will provide data and information on the Amazon forest and climate change information for the Amazon basin. The door has also been left open for cooperative projects with neighboring countries. Technical assistance and training have been offered. A second Latin American center is also being discussed with member countries of the Caribbean Action Plan; and the present thinking is that the center should be located at the University of the West Indies, a regional academic institution similar to the University of the South Pacific in Suva, Fiji. The new center may be opened in late 1992, but more likely it will open in early 1993 due to budget constraints.[3] While progress has been slow in Latin America in the past, it does appear to be moving rather well at the present.

While a number of U.S. organizations, both government and nongovernment, have provided support to the GRID activity since its inception (see Background section), the first GRID Center in North America was not opened until January 1, 1991. The center, identified as GRID-Sioux Falls and located at the U.S. Geological Survey's (USGS) Earth Resources Observation Systems (EROS) Data Center, is supported by both the USGS and the National Aeronautics and Space Administration. The University of California at Santa Barbara and the University of New Hampshire are also active partners in the North American operations of GRID. GRID-Sioux Falls addresses all three of GRID's long-term objectives:

1. It is a major contributor of regional and global data sets and, therefore, plays a significant role in making environmental data available to the world community through the GRID network.

2. It supports the transfer of technology via the GRID networks to other United Nations agencies, intergovernmental organizations, and national governments by sharing its in-house technology development results with UNEP.

3. It provides specialized training, supported by the United Nations, in remote sensing applications for environmental assessment and monitoring programs to developing-country personnel.

The center in Sioux Falls, unlike other centers that are funded by individual countries, does have a resident full-time liaison officer on assignment from UNEP to coordinate the many activities in data-set production, technology development, and scientific studies that are provided by the U.S. consortium.

Thus, the institutional mechanisms for data capture and distribution, while incomplete from a global perspective, are certainly developing at an increasing pace; this does not appear to be the limiting factor

[2] The agreement was signed as scheduled. *Ed.*

[3] The establishment of the center is in progress following the signing of the above-referenced accord. *Ed.*

various centers. This requirement was recognized in the beginning and was included in the initial plan by NASA. In 1986 NASA contributed six C-band ground stations to UNEP/GRID with a network design that would have used two of the stations for the GRID centers in Geneva and Nairobi and a third at a selected NASA center. The remaining three stations were to be used as the network expanded. After much negotiation with the Public Telephone and Telegraph (PTT) authorities in Switzerland and an agreement with Intelsat for a one-year experiment, the entire project was lost due to the unexpected failure of the Intelsat IV satellite series. The ground stations were not upgradable to the Intelsat V series, and the NASA communication program was suspended for new projects in this time frame. The idea was not lost, however, and the European Space Agency (ESA) has over the past four years developed a project called "MERCURÉ" that will provide two-way data transmission among the GRID centers in Geneva, Nairobi, and Bangkok and low-cost receive-only stations for subregional and national centers. In addition NASA has a 1992/93 initiative for a data transmission link between GRID/Sioux Falls and GRID/Geneva, which would complete the primary data network.

SUMMARY

The GRID Programme was initiated in 1985 as a pilot project with no line-item funding within the UNEP/GEMS budget. It has struggled against many elements of funding, personnel, and political constraints over the past seven years; and today it is one of the major Programme Activity Centers (PAC) of UNEP, fully institutionalized with its own budget. The first three years were used to develop policies and procedures, with some significant efforts on building the data holding to an initial critical level. The next four years were spent developing the institutional mechanism for data capture and distribution. Through both of these periods, far too much time was lost struggling with obtaining and maintaining adequate hardware and software systems to record, process, and distribute the data. Now that some sort of institution exists in most regions of the world and the data transmission network is being implemented, it is time for GRID to turn its attention to a more intense data capture activity that will cause accurate high-resolution data to flow from the locals in every country to form more precise data sets for global studies and to cause the data sets from all sources to be readily accessible to scientists and resource managers around the world. This data flow along with a flow of appropriate technology to make best use of the data for improvement of the world's environment continues to be the ultimate objective of the GRID activity.

Persons interested in contacting elements of the

GROWTH HISTORY OF GRID

Figures are approximate

Biennium	86/87	88/89	90/91	92/93
Funding (UNEP Only)	900K	1800K	2600K	6950K
Professional Staff	10	20	28	31
Participating Centers *Some UNEP funding †Staff included in above numbers	Geneva*† Nairobi*†	Geneva*† Nairobi*† Bangkok*† Arendal†	Geneva*† Nairobi*† Bangkok*† Arendal† Sioux Falls*† ICIMOD Tsukuba Warsaw	Geneva*† Nairobi*† Bangkok*† Arendal† Sioux Falls*† ICIMOD Tsukuba Warsaw SPREP* Moscow CAP/CRU Brazil FRG Baltic Basin
Organizational Status Within UNEP	Pilot Project Hidden in GEMS/PAC Budget No Line Funding	Pilot Project in GEMS/PAC Budget Line Funding	Project in GEMS/PAC Budget (implementation phase) Line Funding	GRID/PAC Program PAC Funding

best use of the data for improvement of the world's environment continues to be the ultimate objective of the GRID activity.

Persons interested in contacting elements of the present GRID network should use the following information:

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   Fax: 254-2-226491

3. GRID/GENEVA Facility Manager - Geneva, Switzerland
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4. GRID/BANGKOK Facility Manager - Bangkok, Thailand
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5. GRID/ARENDAL Facility Manager - Arendal, Norway
   Mr. Olav Hesiedal
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6. GRID/ICIMOD Facility Manager - Kathmandu, Nepal
   Mr. Surendra Shrestna
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   Fax: 907-1-524509

7. GRID/TSUKUBA Facility Manager - Tsukuba, Japan
   Dr. Shuzo Nishioka
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8. GRID/WARSAW Facility Manager - Warsaw, Poland
   Mr. Marek Baranowski
   Telephone: 48-22-264231, Ext. 331
   Fax: 48-22-270328

9. GRID/SIOUX FALLS Facility Manager - Sioux Falls, United States
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Overview of Geographic Information Systems Technology in Utah State Government

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Abstract

In Utah state government, geographic information systems (GIS) technology *means much more than a spatial analytical tool used for special projects. Properly implemented and managed, GIS technology can help provide effective workflow, information management, interagency coordination, and a uniform decision-support base. GIS can continually help improve operational efficiency and effectiveness.* Using GIS successfully *means to integrate the technology with the organization's operations to expedite strategic objectives. Organizational management's involvement in implementing GIS is essential to assure its becoming part of the organization's operation.*

Achieving consensus in the use of GIS technology among state government departments and their divisions is important in developing, adopting, and sustaining a statewide GIS strategic plan. The success of the plan relies on attaining common objectives for GIS technology. This paper is written mainly to provide an overview of the established organization and structure in Utah state government for implementing GIS technology and is intended to stimulate thinking about GIS issues, with a focus on ideas that could be valuable or events that some may regard as important.

INTRODUCTION

A goal of Governor Norman H. Bangerter's administration is to "manage state information in a manner that will promote efficiency and effectiveness." The coordination of geographic information systems (GIS) focuses on implementing the technology to help integrate the state's information into a cohesive and manageable resource. Interagency sharing of uniform, accurate, and reliable geographic information and the management of this information as a resource will help promote efficiency and effectiveness in state government.

GIS, a computer technology, was developed with land planning and management in mind. Its applications and graphical output are based mainly on geographic and cartographic principles. The graphic or map features, such as a line representing a road, are characterized by subject-related descriptions and values. Today, the limitations of GIS seem bounded only by our imagination. For instance, efforts are now under way to map the human body using GIS concepts.

GIS-formatted information offers a more practical way of managing information than by traditional data processing methods. Information is stored, maintained, and retrieved by arranging it into themes of information. This thematic indexing reduces information into principal subjects that are easily recognized (e.g., roads, streams, etc.). Additional characteristic labels or values are associated with attribute tables. To perform analysis, themes are combined or overlaid with other themes by the computer. Examination of the resulting product can provide new information on how the themes influence one another. Many combinations may occur; however, each theme's identity is uniquely retained by its attributes for updating or modifying. Cataloguing data by its dominant theme or classifying it by its attributes renders a simple method by which to manage information.

Because GIS geographically references information to the earth's surface, it technically offers an effective way for exchanging or sharing disparate data, one of many reasons for its growing popularity as an information-resource system at most levels of government. Historically, GIS has been used in Utah's state government executive branch for over a decade (refer to Appendix A). Its use has varied over these years among special-interest groups. At first there were signs that GIS would be accepted and used throughout state government: This trend later declined. Today, state government has a renewed interest in GIS, and this time it involves organizational management. As state agencies plan to invest in GIS, its procurement and implementation will be carefully monitored. This is necessary to assure adherence to established state information technology policies, procedures, and standards.

Investments in GIS by local governments are occurring along Utah's highly populated area known as the Wasatch Front (refer to Appendix B). Presuming local governments eventually will become primary producers of GIS information, planning for future compatibility would be advantageous. At most levels of local government, there presently exists a lack of GIS technical expertise. Ill-advised purchases of GIS may result in incompatibility, poor systems design, and an unnecessary cost to taxpayers. Because of the state's GIS training and expertise, it is in the state's best interest to use this knowledge for statewide GIS coordination.

There are many advantages to using GIS in state government. How the technology will augment human efforts to pursue effectiveness and efficiency is often overlooked. Properly implemented and managed, GIS technology can help an organization with managing information management, improving its workflow, coordinating among agencies, and providing management with a decision-support base. For state agencies to achieve the desired results needed for management, they must strategically integrate GIS with the organization's operation. Implementing GIS to increase operational management would also provide a basis for statewide intergovernmental coordination through its use.

BACKGROUND

A statewide GIS program has been in the offing for many years. This was a straightforward attempt to encourage state agencies involved in land planning and management to use GIS and to pool their information. Agency participation was voluntary, and the program received support from a state GIS technical center. Ideally, using GIS agencies would increase productivity, improve quality, raise efficiency, and reduce costs. As a result, a repository of geographic and tabular data produced by these agencies would be an information resource to the state and a basis for decision-making. The idea was sound and pragmatic, with similar concepts being initiated by other state governments. Each state had different strategies, but they all had the same objective—to implement GIS to effectively manage and use geographic information as a resource.

In Utah less than 15 percent of all potential state agencies have participated in this statewide GIS effort. The pitfalls and impasses that prevented agencies from participating have been scrutinized for years. Reasons for this lack of participation are budget constraints, lack of organizational support, unskilled personnel, and unfriendly software. Although these are stumbling blocks, the simple point is that state agencies were not in a position to accept or use GIS technology.

An example of this is a state department that had a lot to gain from using GIS but could not commit resources from an encumbered work force to develop the necessary database. It was more practical for the department to wait until the required data became available before even considering using GIS. In other words, like many state agencies the department was barely maintaining the status quo. Before gaining any benefit from its use, implementing GIS would have put an excessive burden on the agency's already deficient resources. Like this example, many state agency's operations are in such a delicate balance that a major investment, such as GIS, could actually do more harm than good to the present workflow.

Collectively storing all GIS information produced by participating agencies and maintaining it as a common data pool was also a good plan. Over time the data would represent geographic information used and maintained by the state. However, there were no predefined objectives to establish data requirements; and special-interest groups produced the majority of data. Therefore, most of the earlier digital products were site-specific, restrictive, and inadequate. State agencies attempting to use the database as it was intended often found themselves creating the data their co-developers were supposed to provide. As a basis for decision support, a corporate database of uniform, accurate, and reliable information is crucial.

Over the years, the use of GIS in Utah state government has mostly been a centralized process. The reason for this has been the availability of GIS software and hardware platforms. Direct access to the technology was remotely achieved by connecting graphic terminals to the central processing unit with a dedicated communication line. Instead of an agency investing heavily in costly computer hardware and GIS software, this process offered an inexpensive and convenient way to investigate or to use the technology. Since the coming of more powerful microcomputers, greater data storage, and cheaper prices, state agencies choosing to use GIS are now managing their own information and administering their own systems. This change is turning the earlier centralized process into a state operation that is both decentralized and centralized.

With the new technology advancements, state departments and their divisions are now able to operate autonomously and also to interact with one another. As each department begins to operate in its own GIS subnet environment, division-to-division intercommunication will increase existing workflows and possibly create new ones. A wide-area network interconnecting the department's GIS subnet systems will also stimulate interaction among departmental divisions. For instance, a division of the Department of Agriculture can connect to any division in the Department of Natural Resources to exchange information or to work on cooperative projects. In addition, the wide-area network enables all participating departments to be connected with the State Geographic Information Database, local governments, universities, or affiliates. Each department's operation is self-contained and cannot be disrupted by a single point of failure from the wide-area network. The first stage of this interdepartmental GIS subnet connection involves the participation of the Departments of Agriculture, Natural Resources, Environmental Quality, and perhaps the Department of Transportation. By using GIS, this departmental connectivity promotes information exchange and sharing, which in turn increases effectiveness and efficiency.

PLANNING

Implementing GIS in Utah state government is now requiring a few guarantees from the agencies. The intention is to increase the probability of success by involving the agency's management. An information technology plan is used for such a reason. This required plan is submitted each year to the State Information Technology Coordinator in the Governor's Office of Planning and Budget. The contents of the plan include *Executive Summary, Current Environment, Planned Environment, Plan of Finance, Agency Approvals,* and *Schedules and Diagrams*. By using this procedure, an agency planning to invest in GIS explains how it is to be used and what it will accomplish before it can be considered for budgeting. This plan requires the signature of the department's executive director.

Typically, implementing GIS has caused changes in the way organizations have operated. Another guarantee, which is more of a commitment, is that the agency will operationally adapt to meet the requirements of the technology to maximize its use. It is necessary for organizational management to acknowledge this change and to be willing to make necessary adjustments. Finally, the agency must accept and learn how to use the technology proficiently. Many attempts to use GIS have failed because the organization's personnel did not accept the technology. Primarily, this is because they did not have the necessary understanding of GIS and the skills to apply it.

Although there are no real guarantees, the commitment of organizational management to a planned GIS program is a good beginning. State governmental agencies planning to integrate the technology with the organization's operations to help facilitate strategic objectives will not only provide a direction for other state agencies but will also help to strengthen and unify Utah's growing GIS communities. For example, prior expectations of a statewide GIS participation have recently been reinforced through the cooperation and support of Utah's county and city governments. Most of Utah's major universities are not only teaching GIS but are also initiating projects that benefit the state. Federal government agencies and utility companies are also taking part by exchanging or sharing information.

OBJECTIVES

It is in the state's best interests to have its departments, supported by their divisions, develop a statewide GIS strategic plan. This plan could be enacted with a memorandum of understanding among the participating departments. The plan's success depends on the state's departments attaining common objectives for using GIS. A prime objective may be sustaining the State Geographic Information Database. This would serve state government as a geographic information repository, clearinghouse, and decision-support base. The means for supporting the database would be to increase the efficiency and effectiveness of an agency's workflow by sharing and using uniform, accurate, and reliable information.

A strategic plan developed by state government would also help Utah's local governments. These entities are seeking technological solutions, using tools such as GIS, to help reduce increasing pressures. A statewide GIS initiative would be a good incentive for conformity, and it would establish a foundation for coordination. As mentioned, local governments probably will become major producers of GIS data. Coordinating planning initiatives now may prevent a later cost burden to Utah's taxpayers for establishing systems integration and information sharing among levels of government.

Information Management

Information is one of the state's largest assets; however, state agencies have been casual about managing it as a resource. To begin managing information, the first process is to conduct an informational-needs assessment. This is a procedure that identifies all information used and produced by state government agencies. It also determines each agency's primary information, which is information used and maintained by the organization to support its operational objectives. If state agencies will undertake this informational-needs assessment and coordinate their evaluations with affiliated state agencies, a large portion of managing the state's information will have been performed.

The next step in managing information would be to resolve the conflicts of interest and to determine who produces or maintains similar informational themes. At this point, duplications of effort are identified and can be minimized through forming cooperative agreements. As a result, each agency's primary information is declared; and other agencies wanting the information know what it is and where to get it. Supplemental information is also identified through this process. If the information does not exist as an agency's primary information, it either needs to be produced or acquired and collectively placed into a corporate repository. The corporate storage for GIS supplemental data is the State Geographic Information Database.

Eventually, GIS technology will help make geographic information in Utah state government a resource that is meaningful and dependable. GIS can definitely improve the management of vast amounts of data, make better use of existing data, and direct processes for future uses of information. The state's information needs to be organized better for use by public and private sectors. *State government must manage its information:* This cannot be overstated. From land use to earthquake preparedness, information that is available, consistent, timely, and reliable will reduce costs, save time, enhance planning and management initiatives, and very possibly save lives. Furnishing accurate and reliable information to the state's decision-makers and policymakers must become a priority. As previously mentioned, a decision-support base has been needed for a long time. A practical effort is now in progress for this to become a reality. Developing the State Geographic Information Database (SGID) is a beginning. What is necessary for it to become functional is the SGID's ability to access the state's information collectively. This information is literally everywhere throughout state government, but the problem is that it needs to be classified and in a uniform format that is accessible. GIS has the capabilities to communicate very complex, sometimes abstract, concepts and relationships to nontechnical people in a visual manner. More importantly, it can illustrate the processes to accomplish proposed enterprises; but GIS cannot economically serve the state's decision-makers and policymakers when the needed information is in an incompatible format.

The database is the main component for GIS technology to perform sophisticated analytical models or even to do simple inquiries. An organization's success in using GIS depends on the accuracy and reliability of its information. These factors, plus the state's investment in collecting and storing information, give purpose to the continued development of a State Geographic Information Database—no matter what future technology may be developing on the horizon. Fundamentally, GIS practitioners in state government must consciously adopt the goal to provide uniform, accurate, and reliable GIS information, which can serve the public and private sectors as a decision-support base.

Sharing Information

Data capture or conversion is the largest initial cost of implementing GIS. Of all the components that comprise the system, developing the database is the most costly. This includes collecting, digitizing or scanning, editing, and formatting data. Converting and formatting data involve 40 to 60 percent of the cost of implementing GIS. The cost is directly related to the accuracy, resolution, and detail of the information requirements, i.e., the higher its resolution and accuracy, the greater the cost. Exchanging or sharing information, both internally and externally, must be made a high priority to offset this cost. In state government, or in any corporate setting, sharing information to reduce costs is essential.

It is not hard to appreciate the wealth of information that could become available through an exchange or share program among state, federal, and local governments. Over a period of time, consistent data mixing would progressively augment the information's quality with uniform results. The savings encountered from using uniform data and producing compatible analysis would be startling.

The following list outlines other benefits gained from exchanging or sharing information:

1. Increasing productivity
2. Enhancing data-management practices
3. Reducing duplication
4. Promoting data recording and maintenance
5. Initiating cataloging and data lineage
6. Providing a common geographic reference base
7. Defining jurisdictional overlaps
8. Standardizing data dictionaries and indices
9. Identifying data needs
10. Elevating data quality and accuracy standards
11. Distinguishing inconsistencies
12. Helping to establish information ownership

ORGANIZATION

Utah's investment in GIS and the development of its technical expertise started as a concept to establish a state data center. As a result of the state's commitment, there has been widespread use of GIS in Utah and an increased cooperation in data exchange in Utah's public sector. This is not to say that the process of implementing GIS in state government has been uncomplicated, nor was it a naive task to position the technology within a state organization to observe its potential capabilities. A long-time proponent of GIS in state government has been the office of the State Information Technology Coordinator. Any credit for the organization of GIS within state government must be given to this office for those efforts and accomplishments.

State Information Technology Coordinator

The office of the Information Technology Coordinator was established in 1981 when the Department of Systems Planning was abolished and the Department of Administrative Services was created. The responsibilities of state government's systems planning were vested in the coordinator. Duties, at that time, included computer policies, planning, and the review of capital acquisitions and budgets. Today, the coordinator's office is in the Governor's Office of Planning and Budget. Duties have expanded to include all aspects of information technology and its use in state government. Harold D. Carpenter has been the Information Technology Coordinator, previously the Data Processing Coordinator, since 1981. In addition to the coordinator, the office consists of seven staff members. A small audit staff that conducts performance audits has been the most recent addition. The statute establishing the coordinator's office and its designated duties is represented in the following:

In accordance with Utah Code, Section 63-1-32, as enacted by chapter 257, Laws Of Utah 1981, the Information Technology Coordinator, who shall be located within the Office of Planning and Budget, shall be appointed by the Governor of Utah with the following defined authority:

1. The Information Technology Coordinator shall

   A. Develop specific objectives and policies to guide the development of information systems, procedures, and standards within state government to achieve maximum economy and quality while preserving optimum user flexibility
   B. Coordinate the preparation and review of agency information technology plans, encompassing both short-term and long-term needs
   C. Facilitate the implementation of agency plans
   D. Require each state agency to submit annually an agency information technology plan containing the information required by Subsection (2) no later than the June 15 before the legislative session in which the budget request will be heard to the state information technology coordinator
   E. Upon receipt of a state agency's information technology plan, provide a complete copy of that plan to the director of the Division of Information Technology Services
   F. Establish uniform information technology standards and procedures for appropriate interchange of information, optimum service, and minimum cost
   G. Establish policies for costing all information technology services performed by any state information-technology, cost-recovery center so that every cost-recovery center charges its users a rate for services that is both equitable and sufficient to recover all the costs of its operation, including the cost of capital equipment and facilities

H. Establish general policies governing coordination, cooperation, joint efforts, working relationships, and cost accounting relative to the development and maintenance of information technology and information systems
I. Establish priorities in terms of both importance and time sequencing for the development and implementation of information systems
J. Approve or disapprove and coordinate the acquisition of information-technology equipment, telecommunications equipment, and related services for all agencies of state government
K. Monitor information systems development to promote maximum use of existing state information resources
L. Develop policies to ensure the protection of individual privacy and guarantee the exclusive control to a user of its own data
M. Advise the governor on information-technology policy and make recommendations to the governor regarding requests for appropriations for information technology equipment and personnel
N. Maintain liaison with the legislative and judicial branches, the Board of Regents, the State Board of Education, and local government to promote cooperation and make recommendations regarding information resources.
O. Conduct performance audits of state information technology resources in accordance with generally accepted auditing standards and distribute copies of the audit reports as provided in Subsection (3) and
P. Prepare an annual report to the governor and to the Legislature's State and Local Affairs Interim Committee that
   a. Summarizes the state's current and projected use of information technology and
   b. Includes a description of major changes in state policy and a brief description of each state agency's plan

2. Each state agency information-technology plan shall include

   A. Detailed information specifying
      a. The use of existing information technology
      b. The projected use of existing technology
      c. The projected use of any newly requested or acquired information technology and
   B. A detailed review of the agency's use of its information technology during the last calendar year and how that use compares to the plan for that information technology

3. Upon completion of an audit report produced under authority of Subsection (1)(o), the coordinator shall

   A. Provide copies of all audit reports to
      a. The agency audited
      b. The governor
      c. The Office of Legislative Fiscal Analyst and
         (i) Present the performance audit findings to the Information Technology Review Committee at its next meeting
   B. Each state agency shall provide the coordinator with complete access to all information-technology records, documents, and reports, including electronic, analog, or digital, when requested for the purpose of a performance audit.

4. The rate for services established by an information-technology, cost-recovery center, and reviewed by the State Information Technology Coordinator, may be lowered if the Legislature appropriates monies to the cost-recovery center for the specific purpose of lowering rates.

5. The Information Technology Coordinator shall create a Policy Advisory Committee composed of representatives of state agencies.

   A. The Policy Advisory Committee shall
      a. Evaluate and approve or disapprove recommended policies to govern the operation of information technology in state government
      b. Review analyses, recommendations, and critiques of agency plans to ensure that these plans are the most economically viable and are the best solution to the agency's needs and
      c. After consideration of all analyses, recommendations, and critiques, approve or disapprove agency information-technology plans

6. State agencies shall comply with the policies and standards established by the State Information Technology Coordinator and approved by the Policy Advisory Committee.

INFORMATION TECHNOLOGY REVIEW COMMITTEE

The Information Technology Review Committee (ITRC), formally known as the Data Processing Review Committee (DPRC), was created by statute in 1981 as a policy advisory committee. Committee members provide overall leadership and coordination of state information-resource management. The committee reviews and approves or disapproves state agency's information-technology plans and issues policies, procedures, and guidelines to assist agencies in achieving integrated, effective, and efficient information-resource management (IRM Basic Principles 1985). The committee is composed of voting representatives mostly from the state's executive branch. Regularly scheduled meetings are conducted every second Thursday of the month from 8:30 A.M. to 12 noon. Meetings operate by an established agenda and minutes are recorded and available. The chairperson is Harold D. Carpenter, State Information Technology Coordinator.

State GIS Coordinator

The position of State GIS Coordinator was established in the Governor's Office of Planning and Budget in 1989. The GIS coordinator operates under the auspices and direction of the State Information Technology Coordinator. The designated mission is to encourage and coordinate the effective use of geographic information system (GIS) technology in Utah and to direct this purpose in state government. The duties and responsibilities of the GIS coordinator are similar to those of the information-technology coordinator but are related only to GIS. Brent R. Jones, former director of the Automated Geographic Reference (AGR), accepted this position on November 7, 1989. The following adopted principles and objectives establish the duties of the state GIS coordinator:

1. Establish and administer the State GIS Coordinator's Office to include at least the following:

   A. State GIS Coordinator's operating budget
   B. Review and comment on annual information-technology plans associated with the procurement of GIS hardware/software
   C. Help accomplish the objectives of the GIS Coordinator, enter into memoranda of understanding, contract, or cooperative agreement for the development of
      a. State GIS policies, procedures, and standards
      b. A State Geographic Information "corporate" Database
      c. A "friendly" environment for nontechnical persons to access and query the State Geographic Information Database
      d. GIS technical support as defined
      e. State government's use of GIS technology through research and development.

2. Provide leadership in the development and effective use of GIS:

   A. Within the limits of available resources, support state and local governments, regional and local planning organizations, and private business and industries active in GIS technology
   B. Coordinate planning for GIS activities within state and local governments to assure compatibility
   C. Assist state agencies in developing a strategy, plan, and budget for implementing GIS technology
      a. Examine problems and pitfalls of new GIS installations, thereby providing "support systems" for struggling GIS organizations or those who are embarking on GIS applications
   D. Promote GIS research and development to fulfill current or planned applications
   E. Increase the awareness and understanding in state and local governments of the concepts associated with the sharing of geographic information
      a. Encourage data-exchange initiatives among federal, state, and local governments and the private sector
      b. Promote intergovernmental data exchange to help avoid duplicate investments in similar data
      c. Encourage cost-share initiatives for mutually beneficial GIS automation or production activities

3. Create and staff a State GIS Advisory Committee to serve in the following capacity:

   A. Advise the State GIS Coordinator
   B. Oversee the State Geographic Information Database
      a. Review and recommend priorities for state GIS project development
   C. Review and establish state GIS policies, procedures, and standards
   D. Evaluate "State Critical Issues" relevant to GIS and provide recommendations

4. Develop and maintain a State Geographic Information Database (SGID) to serve in the best interest of the state as subscribed by the State GIS Advisory Committee:

   A. Establish as an impetus for GIS policies, procedures, and standards
      a. A policy for state agencies to provide

their own adopted standards for the State Geographic Information Database data dictionary
   b. State and local government authorities of qualifiable information
B. Establish a central repository for sharing or exchanging GIS or digital cartographic data
C. Establish procedures to manage and monitor statewide GIS data production
D. Define base layers of applicable geographic information required by state agencies using or planning to use GIS technology

5. Establish state GIS policies, procedures, and standards to include at least the following:

   A. State Geographic Information Database data collection and storage formats
   B. Data interchange formats
   C. GIS-distributed network systems physical-transport standards

GIS ADVISORY COMMITTEE

On April 12, 1990, the GIS Advisory Committee was established as a subcommittee to the Information Technology Review Committee. Its purpose was to address GIS issues and to develop standards, policies, and procedures. The committee's initial nine voting members were comprised of state and local government representatives. Membership has since increased to twelve, which includes a representative from the State Legislative and General Counsel and from the U.S. Geological Survey. Meetings are regularly scheduled for every third Thursday of the month from 2:00 P.M. to 4:00 P.M. Meetings are open; they operate by an established agenda; and minutes are recorded and available. The chairperson is Brent R. Jones, State GIS Coordinator.

AUTOMATED GEOGRAPHIC REFERENCE CENTER

Located on Capitol Hill, the Automated Geographic Reference Center (AGRC) is the manager of the state's central GIS repository and clearinghouse. This is a statewide effort referred to as the State Geographic Information Database (SGID). Although it is still in development, the SGID has already gained tremendous support and recognition from both the public and the private sectors.

AGRC has been a recognized leader in GIS both statewide and nationally. It represents the state's technical arm by providing leadership in applied GIS technology. AGRC conducts research to investigate GIS applications and develops GIS programs and procedures to enhance the utility of GIS in the state of Utah. The center offers GIS technical services, training, and support to federal, state, and local government agencies and to the private sector on a cost-recovery basis.

AGRC responds to its clients needs with an experienced staff of seven GIS professionals with experience in project management and applied GIS technology. The staff members are from a variety of different professional backgrounds other than GIS. Through combining their learned professional skills with expertise developed in GIS applications and utility, AGRC's staff offers a high level of GIS services to professionals and scientists involved in land planning, management, and research.

AGRC's clients are offered a broad range of GIS professional services in the following areas:

1. Strategic and tactical planning

2. Needs assessment

3. Systems planning and design

4. Database design and development

5. Project and production management

6. Spatial and statistical analysis, including:

   A. Area measurements
   B. Linear distances
   C. Categorical clustering
   D. Impact assessment
   E. Suitability modelling
   F. Preferred alternatives
   G. Proximity evaluations
   H. Future conditions
   I. Network routing, allocation, and districting
   J. Slope, aspect, volume, profiling, and surface length determination
   K. Visibility assessments
   L. High-level computer applications programming
   M. User-friendly interface, including
   N. Fourth generation programming (AML/SML)
   O. Custom menus
   P. Data capture and conversion
   Q. Geometry applications coordination
   R. Map design and production
   S. Prepress lithographic products
   T. Statistical report generation and documentation
   U. Professional GIS training and workshops

In 1990, AGRC administratively moved from the Governor's Office of Planning and Budget to the Department of Administrative Services, Division of Information Technology Services. This allowed AGRC to fully operate as a GIS service bureau to all branches of state government. This reorganization permits AGRC to increase its dedication to its clients with high-quality innovative GIS services. The manager of AGRC is Dennis B. Goreham.

State Geographic Information Database

The State Geographic Information Database (SGID) was established on June 7, 1990, by the State GIS Advisory Committee. The purpose of the SGID is to serve the state of Utah as a geographic-information data-resource center. Its overall objective is to furnish Utah's decision-makers and policymakers with comprehensive and organized geographic information that is uniform, accurate, and reliable. Presently, AGRC houses the largest portion of collected GIS data. In a broad sense, GIS data will not just reside at AGRC. Technically, the SGID consists of all accessible primary data from participating agencies, plus that of AGRC's, interconnected by a wide-area network.

Utah's Information Resource Management Master Plan, 1986, designates state departments and their divisions with the responsibility of maintaining their own information. Information an agency collects, compiles, originates, and maintains as a resource to help it accomplish its objectives or mission is considered primary data. Many state GIS programs will require more data subjects than those made available as primary data. These additional data provisions will be needed to perform spatial analysis and to provide map products. For this purpose, AGRC will augment the SGID's data provisions by providing state agencies with supplemental data. AGRC will maintain and provide supplemental data that are significant and relevant for GIS analysis but do not duplicate an agency's primary data.

The SGID functionally operates as the state's GIS information resource-management system, data repository, and clearinghouse. Perhaps more importantly, additional strategic factors are (1) to advocate the effective use of GIS in the state of Utah; (2) to provide a common link for integration of disparate tabular data; (3) to affiliate the state's existing policies, standards, and procedures and to help fashion their formation; and (4) to help serve the state's GIS wide-area network in interagency data transmissions and applications sharing.

In February of 1991, the Utah State Legislature passed Senate Bill 21, Geographic Information Systems Data Sharing and Conformity. This bill, in effect, creates some permanency in state government for the State Geographic Information Database and establishes the Automated Geographic Reference Center as its manager. This was significant and denotes Utah's legislative branch as advocates of GIS technology as an informational resource.

STANDARDS

It is common knowledge that establishing standards for GIS implementation would maximize integration and facilitate interoperability. The term *standard* is a major topic and concern of GIS practitioners, especially at the regional and local levels of government. Conforming to an established process that results in uniformity is essential for organizations considering or implementing GIS technology.

A myriad of GIS standards issues needs consideration. To help determine areas of responsibility for establishing GIS standards, the following functional categories of GIS are offered:

1. Hardware platform and peripherals
2. Software platform and related applications
3. Data structure and management
4. Physical connections and data transports

Hardware/Software

Standards become most effective in reducing costs when hardware and software products must be linked or when exchanging or sharing information. The term *open standards* is often misused by some computer vendors. Their purpose is to get prospective customers believing that full integration among all computer manufacturers is now happening. A large part of the computer industry is making strides toward these goals; but until full integration among incompatible systems is available at a reasonable cost, state GIS standards will be enforced to protect the taxpayers and their investments. To sustain the implementation of GIS and advance its effective use in Utah's state government, the following standards have been established:

1. GIS Software: ARC/INFO, developed by Environmental Systems Research Institute
2. GIS Hardware: Sun Microsystems 32-bit UNIX based SPARCstation1+, and
3. Operating System: UNIX

Primary Information

The agency's continuous use and maintenance of primary data progressively increases the quality and accuracy of this information. Eventually, the agency becomes the state's recognized authority; and the information's characteristics become a standard for that specific information theme. For large departments, the value of such a resource becomes apparent when subordinate divisions incorporate each other's primary data for planning and managing purposes. The organization and management of primary data that is uniform, accurate, and reliable will also be reflected in the tactical and strategic planning of the organization. Managing primary information and integrating it with traditional data processing information can provide greater operational efficiency and mission effectiveness.

Distributed GIS Network

The state recently released a Request For Proposal (RFP) for a Statewide Interconnect Network. Until a purchase agreement is awarded and networking standards have been established, the following standards are recommended for distributed GIS networks and high-speed transmission of graphical data:

1. Operating system: UNIX
2. Application layer: NFS (TCP/IP)
3. Physical layer: Ethernet
4. Building wire: Twisted pair

FUTURE TRENDS IN GIS

In the mid 1980s, an interest in GIS at the regional and local government levels started to escalate. Urban planners discovered GIS as a cost-effective tool for land planning and managing. The need for an efficient and effective means to manage and maintain parcel-level mapping and associated records was realized by the use of GIS. This trend should continue to grow through the nineties, and regional and local government agencies will eventually become the largest users of GIS.

As the goals of urban planners become accomplished by developing databases for their own use, they will also become the major producers of explicit GIS data. A reason for this perception is due to the present lack of available data at these levels. If the regional and local government agencies gain the needed support for appropriations to invest in GIS, it is also reasonable to predict that many federal and state government entities will become users of their data.

With the possibilities of federal, state, and local government cooperative efforts in the exchange and sharing of GIS information in Utah, a concept called GIS multiparticipant project could become a strategic statewide planning tool. This integration of GIS resources could be organized as a cooperative effort involving a few agencies or more than a dozen often diverse agencies. It could provide the means to have access to a geographic information association of legally separate professionals. For the participants, it may provide an economical business opportunity or a process to gain some political clout.

This operational arrangement could provide a consortium of professional and technical expertise representing both the public and private sector (Montgomery 1990). Through this type of cooperative effort, access to existing information and planned land-management practices could become invaluable to overall planning efforts. Besides the information and professional capabilities, administrative coordination and support could be sought from all levels of government involved. A GIS multiparticipant project could be a first step in providing a vehicle for public support for such proposed enterprises as sponsoring the Winter Olympic Games.

SUMMARY

As organizations continually strive to improve the efficiency and effectiveness of their operations, they often turn to technical solutions for an answer. As a result, modern technology can increase efficiency; but by itself it cannot improve the effectiveness of the organization. This responsibility is the organization's: It must conduct its business practices to meet the requirements of the technology.

Issues pertaining to people, organizations, and data must be resolved by management. As stated by Eric Strand, "GIS is a technology with identifiable functional relationships among the various components that comprise the system—people, organizations, data, software, and hardware. Problems with acquisition, implementation, and application of GIS software and hardware yield to technical solutions."

Although it is understood that GIS is referred to as a tool for land planners and managers, its method of managing information can also be used to augment operational management effectiveness. Organizations implementing GIS must manage their information to provide a direction for GIS that will be successful. The basic elements for successful GIS implementation are that (1) the system accomplishes the specified purpose for its acquisition, (2) personnel accept the technology and learn to proficiently use it, (3) normal work activities ensure data quality improvement, and (4) GIS projects are completed on time and within the designated budget.

As appropriately stated by Barbara Gole, "The interrelationship between the organization's success in changing to meet the technology's implementation requirements and the technology's success in meeting the organization's goals cannot be overstated. The behaviors required for implementing a GIS project successfully and those necessary for achieving general departmental strategic goals are complementary."

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APPENDIX A: CHRONOLOGY

1979: State of Utah becomes interested in Geographic Information Systems (GIS) technology as a planning and management tool. State Planning Coordinator, Office of Planning and Budget, takes lead role in a feasibility study.

1980: To evaluate the utility of GIS technology, state contracts Environment Systems Research Institute (ESRI), Redlands, California, to provide a visibility assessment of the proposed Alton coal field as a GIS pilot project.

State Planning Coordinator contracts ESRI to provide a conceptual design and implementation plan for a geographically based data-information system.

1981: Initial purchase of ESRI's GIS software called "Polygon Information Overlay System" (PIOS). PIOS was ESRI's first commercial polygon handling system developed, which became a model for nearly all subsequent commercial, research, and development efforts in GIS.

State contracts ESRI to port PIOS GIS software to state's IBM mainframe using WANG as a remote job entry.

1982: Automated Geographic Reference (AGR) established in the Department of Natural Resources to implement GIS. Mission focused on Department of Natural Resources. Riki Darling, Utah Geological and Mineral Survey, assigned as first AGR director.

ESRI releases first development of ARC/INFO GIS software, version 2.0. This was a major breakthrough in geoprocessing software, resulting in a generic software product that would incorporate modern principles of database management systems, computer graphics, and cartographic theory.

1983: GIS Steering Committee created to assess GIS and its utility in state government.

AGR adopts U.S. Geological Survey Topographic Map Series, 1:24,000-scale, as official manuscript and compilation map.

1984: State purchases ARC/INFO version 2.0 GIS software to operate on a Prime mini-computer, model 550-II., Primos operating system.

AGR administratively remains in the Department of Natural Resource; but with additional personnel from the Office of Planning and Budget and Division of Data Processing, it is physically moved to Capitol Hill to become the AGR task force. The task force is charged with evaluating the and organizational issues of GIS implementation in state government. AGR's mission changed to a statewide focus and applied GIS project development.

State contracts Price-Waterhouse to evaluate "A Strategic Approach" to the AGR Program.

1985: Department of Natural Resources, Division of State Lands and Forestry, becomes the first GIS remote site.

AGR wins two international ESRI competition awards: Most Analytical Award for Proposed Nuclear Waste Repository Site Visibility Assessment and Most Communicative Award for AGR's Map Production Macro.

1986: AGR reorganized under the Governor's Office of Planning and Budget. Mission expands to include statewide GIS leadership and GIS service bureau/sale of services. Michael Johnson, Office of Planning and Budget, assigned as director.

1987: State awards purchase agreement to ESRI for its response to the "Geographic Information Systems Integration and Growth" request for proposal.

Department of Natural Resources, Division of Water Resources, becomes GIS remote site.

AGR upgrades Prime computer to a model 4150.

AGR contracts U.S. Geological Survey, Rocky Mountain Mapping Center, by cost-share agreement, to produce official state of Utah digital map at 1:500,000-scale.

U.S. Department of Agriculture, Soils Conservation Service, becomes GIS remote site.

Department of Economic Development, Division of History, becomes GIS remote site.

1988: Michael Johnson leaves AGR. Brent Jones, AGR, assigned as interim director.

U.S. Forest Service, Region IV, Ogden, Utah, becomes GIS remote site.

Department of Health, Division of Environment Quality, connects to AGR's Prime Mini-computer via X.25.

1989: Jeannie Watanabe, Office of Planning and Budget, assigned to assist AGR's management and evaluate ARC/INFO software platform on the state's IBM mainframe for statewide access.

"AGR Strategic Plan" identifies AGR as functioning under dual mission: (1) GIS projects and service oriented and (2) provides statewide leadership in GIS.

November 7: State GIS coordinator position created in Governor's Office of Planning and Budget. Mission focused on state GIS leadership. Brent Jones, AGR, assigned to position.

1990: AGR reorganized July 1 under the Department of Administrative Services, Division of Information Technology Services, to become Automated Geographic Reference Center (AGRC). Mission focuses on applied GIS technology as a service bureau/sale of service. Dennis Goreham, AGRC, assigned as manager.

April 12: Information Technology Review Committee approves ARC/INFO as the state's GIS software standard. State GIS Advisory Committee, as a subcommittee, addresses GIS-related issues.

May 20: Sun Microsystems awarded state purchase agreement, by choice, for its 32-bit UNIX-based SPARCstation1+, resulting from high-performance GIS workstation request for proposal.

June 7: State GIS Advisory Committee approves

1. Principles and objectives of the state GIS coordinator
2. State Geographic Information Database (SGID) as the state's GIS repository and clearinghouse to be managed by the Automated Geographic Reference Center
3. SGID as impetus for developing statewide GIS policies, procedures, and standards
4. Sharing of GIS and related information as the state's GIS plan

July 1: State GIS Coordinator contracts AGRC to develop and manage the State Geographic Information Database (SGID) and to complete the following tasks:

1. Provide a geographic data inventory and data availability catalog
2. Establish GIS data dictionary standards
3. Develop a 1:24,000-scale library
4. Develop a 1:100,000-scale library
5. Develop a 1:500,000-scale library
6. Develop a statewide county tile library
7. Provide user-friendly, menu-driven access to SGID
8. Establish cost of storing SGID on Prime 4150 mini-computer
9. Investigate preserving obsolete GIS data
10. Recommend salary, costs, and duties for a database administrator

1991: Legislature enacts Geographic Information Systems Data Sharing and Conformity bill, Utah Code, Section 63-1-32, an act relating to geographic information, providing for its contents and management and mandating state

state agencies to comply with policies and standards approved by the Information Technology Coordinator. A concurrent resolution enacted by the legislature and governor forms a Geographic Information Council. This council creates a nucleus for all geographic information disciplines to communicate and share information.

APPENDIX B: GIS AND RELATED TECHNOLOGIES IN UTAH

Federal Government

Bureau of Land Management
Software:MOSS, developed by U.S. Army
U.S. Air Force (Hill Air Force Base)
Software:PC ARC/INFO, ESRI
U.S. Army (Dugway Proving Ground)
Software:PC ARC/INFO, ESRI
U.S. Forest Service
Software:Intergraph, Intergraph Corporation
ARC/INFO, ESRI - Remote user
U.S. Geological Survey, Water Resource Division
Software:ARC/INFO, ESRI
U.S. National Parks Service
Software:PC ARC/INFO, ESRI
GRASS, U.S. Army
U.S. Soils Conservation Service
Software:ARC/INFO, ESRI - Remote user
GRASS, U.S. Army

State Government (Unlisted software indicates agency is using ARC/INFO)

Department of Administrative Services
Division of Information Technology Services
Automated Geographic Reference Center
Division of Facilities and Construction Management
Software:AutoCAD, AUTODESK
Department of Agriculture
Software:ARC/INFO, ESRI (proposed)
Division of Plant Industry
Software:SPANS, TYDAC Technologies, Inc.
Department of Economic Development
Division of State History
Department of Environmental Quality
Department of Natural Resources
Division of Oil, Gas and Mining
Software:AutoCAD, AUTODESK
Division of Parks and Recreation
Software:AutoCAD, AUTODESK
Division of State Lands and Forestry
Division of Water Resources
Software:PC ARC/INFO, ESRI
Division of Water Rights
Division of Wildlife Resources
Software:PC ARC/INFO, ESRI
Utah Geological Survey
Software:AutoCAD, AUTODESK
Department of Public Safety
Division of Comprehensive Emergency Management
Software:IEMIS (hybrid), FEMA (public domain)
Department of Transportation
Software:DIGIMAP, DIGINETICS, Inc.
Legislative Research and General Counsel

University or College

Brigham Young University
Software:ARC/INFO, ESRI
Intergraph MGE, Intergraph Corp.
University of Utah Geography Department
Software:ARC/INFO, ESRI
Utah State University Geography Department
Software:ARC/INFO, ESRI, ERDAS
Weber State University Geography Department
Software:PC ARC/INFO, ESRI

County Government

Davis County
Software:Geo Graphics (in-house)
ARC/INFO, ESRI (proposed)
Salt Lake County
Software:ARC/INFO, ESRI
Summit County (proposed)
Software:ARC/INFO, ESRI
Tooele County
Software:PC ARC/INFO, ESRI
Uintah County
Software:ARC/INFO, ESRI
Utah County
Software:ARC/INFO, ESRI
Wasatch County (proposed)
Software:PC ARC/INFO, ESRI
Weber County
Software:AutoCAD, AUTODESK

City Government (ARC/INFO platform)

Draper City
Murray City
Orem City
Salt Lake City
Sandy City (Strings)
West Jordan City
West Valley City

Utilities

Mountain Fuel Supply Company
Software:Intergraph, Intergraph Corp.
U.S. West Communications
Software:ARC/INFO, ESRI
Utah Power and Light Company
Software:GFIS, IBM
Software:ARC/INFO, ESRI

Politically Correct Global Mapping and Monitoring

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Abstract

Global assessments and monitoring are essential if we wish to be able to manage our human destiny. Periodic worldwide estimates of forest resources are the responsibility of the United Nations Food and Agricultural Organization (FAO). Other groups are also making regional estimates of forest cover. Techniques used include aggregation of national data and individual efforts. Results of either process are currently inadequate. Problems with both techniques are presented. Solutions include multiple-resource inventories, covering all lands and performed to international standards and guidelines.

INTRODUCTION

The earth's forest resources provide vital food, fuel, and fiber for an increasing world population. Forests account for about two-fifths of the world land area. In the late 1980s, the direct annual contribution to the economies of developing countries from the forestry sector was about $105 billion (Roberts, Pringle, and Nagle 1991). Forests are both carbon sources and carbon sinks. They serve as filters for the air we breath and for the water we drink. Forests provide critical habitat for diverse flora and fauna that may prove vital for human survival in the future. Forests are also places of recreation, worship, and strength for the inner body.

Forests are also the center of many national and international controversies. Social, economic, and environmental problems in one country can affect the forest resources in another. Drought and civil war in one country, such as Ethiopia, cause populations to move to other areas, such as the Sudan. In an underdeveloped country like Sudan, which cannot support its own increasing population, this emigration creates even greater demands on the land for food and fuel. These must come from the forested lands. Drought in Sudan, coupled with increased deforestation and overgrazing, has reduced the capacity of the land to support its own people much less the immigrants from Ethiopia. As a result, there is also social unrest in Sudan.

Emissions from industrial countries in the temperate areas have been blamed for forest damage in the boreal regions. Currently, the boreal regions are exporters of timber. If emissions are not reduced or if damage should become more severe, the boreal regions may have to start importing. This will put strains on other nations' forestlands.

The setting aside of large land areas in the United States for wilderness and to preserve endangered wildlife species reduces the timber-producing land base. If the U.S. population continues to increase, so will the demand for wood and wood products. To meet these demands, supplies must come from either more intensive use of our private lands or from forest resources abroad, including the tropics.

Deforestation in the tropics may cause global warming. Global warming, in turn, will affect the productivity of forested areas in other parts of the world.

Indeed, the amount and condition of the world's forests are important issues. Unfortunately, global forest resources are dwindling at unprecedented rates in the tropics and are losing diversity and productivity in other areas. The world's forestland must be assessed and monitored. We must establish what we have, determine the trends, and gather data necessary to develop sensible management plans.

Before we go further, however, we need to define some terms:

1. *Politically correct:* Subscribing to an ideological view that has become dominant. To oppose it becomes a subject not open to argument.

2. *Politically correct global monitoring system:* A system in which individual nations and international organizations work cooperatively to produce periodic estimates of the state and trend of the earth's resources. The results are acceptable to all parties involved.

3. *Inventory:* The accounting of goods on hand. Often used as a baseline for subsequent monitoring efforts.

4. *Monitoring:* The periodic measurement or observation of selected physical, chemical, and biological parameters for setting up base lines and for detecting and quantifying changes over time.

5. *Plot:* A known location on the earth's surface having defined boundaries or a point of origin. A *permanent plot* is established and documented in such a manner that one can remeasure the exact area and the same objects at a later time (Lund and Thomas 1989). A plot may not have to be located physically on the ground. One could identify an area on imagery and repeatedly observe the same area over time. Plot size may range in size from 0.1 hectare to a pixel to a Landsat scene to a whole continent, depending on what is to be monitored.

This paper examines current monitoring efforts, identifies problem areas, and offers recommendations for moving toward a politically correct global monitoring system.

CURRENT GLOBAL MONITORING

Because of the recent concerns about environmental issues such as deforestation and global warming, several groups are working to get estimates of planetary carrying capacity and change. These groups include the United Nations Food and Agricultural Organization (FAO) and the European Economic Community (EEC) working in cooperation with FAO. FAO has the mandate to conduct global forest assessments and monitoring (Singh 1992). Obtaining estimates of forest cover and production over the entire earth requires time, coordination, and funding—all of which are often in short supply.

Other groups, such as the European Community TREES project, Conservation International, the United Nations Environment Program, Woods Hole Research Institute, and International Space Year's World Forest Watch, are conducting regional assessments and monitoring programs to speed up the availability of information. In addition, most, if not all, nations conduct their own inventory and monitoring programs. Unfortunately, many of these activities are not coordinated with FAO and contribute little to the total knowledge base needed.

MONITORING APPROACHES

All monitoring efforts involve comparing data from two or more points in time. The comparison data may be in the form of statistical summaries, maps, or remote sensing products. In the past, data were stored in tables and reports. Lately, the trend is to store data spatially in a geographic information system.

The source of baseline information and later assessments may result from aggregation of existing national information in a participatory mode or from a single data collection effort covering many nations.

AGGREGATION

Aggregation of existing information or subinventories is by far the most common monitoring approach for forest assessments of large countries like the United States and Canada and for developing global assessments like those of FAO. A central unit specifies the information needed in the form of tables cooperators must complete. Participating elements collect the data for their areas of responsibility and provide summary information to the coordinating unit. Baltaxe (1992) refers to this method as a bottom-up approach. Even though forests occupy two-fifths of the world's land area, the forestry sector receives only about 4.5 percent of the total FAO budget (Roberts, Pringle, and Nagle 1991). Only a portion of that is allocated to global monitoring. As a result, FAO must rely on cooperation with other countries for forest assessments.

If the collaborating units belong to the same organization as the central unit, there can be strong control. The directing organization specifies end product, sample designs, and data collection techniques and standards. If the participating elements belong to different organizations, such as those found in Canada and Tanzania, the control is less stringent. The accumulating organization specifies data required and indicates when they are required. Participating elements are free to use whatever data collection method they wish, as long as they can provide the necessary data to the required standards needed by the head organization. This is the technique EEC/FAO uses for global assessments of the temperate zones, and it is the most politically acceptable form of global monitoring.

Through the aggregation process, there are

1. Fewer effects on the cooperators. They are free to use whatever techniques are suitable for the environmental, physical, and economic situations they face.

2. Fewer opportunities for conflicting data as the cooperating units provide the data for their lands.

3. Lower costs to the central unit as most of the expense is borne by the participating units.

Aggregation and participatory assessments and monitoring are the most politically acceptable to all parties involved. However, there are some disadvantages:

1. Collaborating elements or the head unit may have to do considerable manipulation of the data before they can be combined and used for national reporting.

2. Data may not be truly additive because of the different standards and techniques used.

3. The quality of the final report is only as good as the weakest participating group.

4. Data from participatory nations are not spatially located. The use of the information in a geographic information system (GIS) is limited.

From a national perspective, aggregation is the most desirable method. Some nations, however, may not take part for several reasons. The country may feel that it already has adequate statistics and that a new effort is not warranted. The country may not have the technology, people, funding, or time to carry out a new initiative; or the country may have statistics that it has been using as a basis for planning, funding, and reporting. New information, contrary to what has been previously reported, may be politically embarrassing to those in power.

Single Effort

Nationwide inventories conducted in one single effort are common in relatively small countries such as Taiwan and Morocco. Lately, the individual effort has become very popular to speed up the effort for collecting multicountry data and to provide maps and spatial databases of the forest resources. Groups using the single effort include the European Community TREES program, United Nations Environment Program (UNEP), Woods Hole Research Institute, Conservation International, and others. Baltaxe (1992) calls this the top-down approach.

Mapping-based inventories rely on remote sensing (aerial photography or satellite-based imagery) to produce type maps or digital databases of forest cover. At a minimum, image interpreters use ground truth to help with the classification. In this case, the primary products of the inventory are the type map or digital database and estimates of forest area. More sophisticated designs use the mapping in poststratification of randomly selected field plots, yielding both maps and the more traditional biomass statistics.

The advantages of the single effort are that the process is fast and that all data are collected within the same time frame and to the same standards. Control is simple and the processing is cost-effective. In addition most data are spatially located, providing direct input to GIS.

Many single-effort, regional-monitoring projects involve wall-to-wall mapping of the forest vegetation. Most statistics developed from aggregation of existing data rely on statistical samples for area estimates. Everything else being equal, one would anticipate better area estimates from the mapping effort than from the sampling method.

Another advantage of the single method, or any method that uses remote sensing for establishing a base, is that if one can find older imagery of the same area the images may be used to detect changes and to predict trends. One may use today's technology to analyze yesterday's imagery.

To date there is no worldwide, individual monitoring activity, although it is probably just a matter of time until there is one. The technology and people having the skills are available. All that is required is time and funding.

Most current, so-called global monitoring efforts concentrate on the tropics and most are independent of one another and uncoordinated (Jaakkola 1992, Stone and Schlesinger 1992). Tschinkel (1992) reports on nine separate efforts in Central America alone. Many of these efforts cover the same area as one another and as available local (national) inventories. As a result, there are confusing and contradictory statistics and maps produced.

There are several reasons for the duplication of inventories and monitoring efforts:

1. Existing work is often out of date or does not answer the questions being asked. A new effort to provide current data is needed and warranted.

2. For one reason or another, the existing work is questionable or not trusted. There is a tendency not to trust government statistics. In reality, however, government statistics may be the most valuable data source.

3. The existing work may be unknown.

4. Researchers want to test new techniques.

5. The survey is not intended to provide objective data. Its main purpose may be to draw national and international attention to gain support for a particular cause.

Knowledge of local conditions is essential if the project is to be successful. Ground truth collected through permanent field plots is needed to determine the accuracy of the databases and to provide information not available from the remote sensing. National participation is certainly desired for these activities.

A primary disadvantage of the single effort is that statistics weaken the further one stratifies the data. For example, if a project involves several countries, the statistics for a specific country may be very poor. In addition the single effort may not make use of good existing information. The results may conflict with existing data at the local or national scale. This can place the local forestry agency at odds with the group conducting the survey. Special-interest groups can then highlight such discrepancies to promote their cause thereby fomenting further discontent.

Avoiding Conflicting Data

Conflicting data are generally not politically correct or acceptable. One may avoid conflicting data if

1. International groups do not report data at the country level

2. All parties develop and use a hierarchical classification scheme that incorporates both global and local standards

3. All parties report statistics separately and clarify any differences if data appear to conflict

COMMON PROBLEMS

There are two major problems concerning regional and global monitoring efforts regardless of whether we use aggregation or individual efforts. These include misinterpretations of data and incomplete information.

Misinterpretations of Data

In the past, most monitoring consisted of periodically comparing aggregations of country statistics over time. With the advent of satellite-based remote sensing, international organizations have been able to assess and map large areas independent of country involvement. Some recent estimates of change have resulted from a comparison of aggregated data with the more recent remote sensing-based estimates. This poses some problems because not only are we comparing data from two points in time we are also comparing data collected by different sampling methods and standards. Consequently, one should view and report the results accordingly. One must determine if the changes are due to actual changes in the resource base or to changes in the technology and standards.

Changes in Techniques

If two people independently map or randomly sample the same area at the same time using identical techniques and standards, the results will differ although the difference may not be significant. If one samples the same area at the same time and even measures the same locations, the totals for the inventory unit may vary depending on the sampling scheme used (Lund and Thomas 1989). Therefore, if we use different techniques at different points in time, we would logically assume there would be differences in the totals reported for each measurement occasion. The question then is this: Are the differences due to changes in the techniques or in the resource base? To avoid this question in the future, we should use the same sampling scheme and permanent plots on both occasions.

Changes in Definitions and Standards

If we used the same sampling design and plots on both occasions, there could be differences in the reported results due to changes in definitions and standards. For example, assume that on the first occasion we tallied trees only if they were 5 meters in height or greater. Further assume that on the second occasion we change the threshold for tallying trees to 7 meters in height or greater. Intuitively, we may expect the results from the second occasion to show less volume than the results from the first occasion.

The definition of *forestland* may also cause problems in comparison of inventories and monitoring. This is especially true where international organizations sum data from national assessments to yield global statistics. In the United States, for example, forestland is an area 1 acre in size or greater and at least 10 percent stocked by trees of any size or formerly having had such tree cover and not currently built up or developed for agricultural use. A tree is defined as a woody plant usually having one or more perennial stems at least 3 inches d.b.h. at maturity, a more or less definitely formed crown of foliage, and a height of at least 16 feet at maturity (USDA Forest Service 1989). This definition includes lands recently harvested or burned over that will be used for forest production but excludes orchards and trees in urban areas.

In Mexico forestlands are any areas that are not in agriculture or urban.

FAO has an international definition. Forestlands are areas exceeding 0.5 hectares in extent or greater with tree crown cover more than 20 percent of area. Trees must be capable of reaching 7 meters in height or greater (Wardle and Padovani 1990). This would include plantations, orchards, etc.

If we were to use Advanced Very High Resolution Radiometer (AVHRR) imagery to classify lands, in all probability we would define forestlands as areas 1 square kilometer in size or larger and stocked with trees having at least 20 percent canopy cover. Lands recently clear-cut and not restocked with trees at the time of data collection would not qualify as forestland.

One can easily see from the above that the estimates of forestland would vary simply by changing the definitions, standards, and technology used. We can overcome some definition problems by statistically field sampling all strata with permanent plots. We use permanent plots to estimate land-cover changes between inventories, to set up a basis for long-term study of the effects of climate change, to monitor response to treatments, and to construct growth and yield predictions (USDA Forest Service 1992). International agencies may use networks of permanent plots to model biological, socioeconomic, and political factors that affect deforestation and eventually reforestation and afforestation. Global positioning systems can be used to accurately determine the location of field plots, thereby linking imagery with ground data in a GIS.

Incomplete Information

Most so-called global efforts focus on forest extent. Area information alone does not resolve issues of biodiversity and carbon storage. A network of permanent field plots will provide details that cannot be extracted from remote sensing.

Until about 1980, most national inventories of forest resources emphasized estimating the amount and extent of the timber resource. Since that time, public interest has placed increasing emphasis on the need to manage public forests for a variety of purposes and to recognize uses that have been ongoing since humans first set foot in the forests. In addition decision-makers are using national inventories for environmental monitoring both at the local scale and at the global level. New needs include information on woody and nonwoody vegetation (kind, extent, production, and condition), soil stability and productivity, water storage capabilities, and wildlife habitat extent and quality on all lands.

OUTLOOK FOR THE FUTURE

We can safely predict that the earth's population will continue to increase and that our land base will remain essentially the same. There will be more pressure on our lands to produce more goods and services. With this pressure it will become increasingly important to maintain or improve soil, water, and air quality. This is most easily achieved by maintaining or increasing world vegetation cover. Within vegetation cover it will be increasingly important to maintain or increase biological diversity and to support economic diversity of the local population. More knowledge about our resources and lands and how they react to various management activities will become increasingly important if we are to support this diversity at the local, national, and global levels. The demands for accurate, spatially located information will increase the use of geographic information systems.

We can also forecast that our technical capabilities to inventory and monitor the lands and resources will also improve. The resolution, spectral separation abilities, frequency of coverage, and overall availability of satellite-based, remote sensing systems will increase. Mapping and monitoring of our resource base will be essential. Our inventories will eventually cover all lands and resources and account for every hectare.

International organizations and cooperating nations need to be working with FAO toward a common goal—that is, to provide a complete picture of the status and trend of the world's forest resources. To do so we need to look at all functions of the forests and the relationship of forestlands to other lands and uses as well.

Multiple-Resource Inventories

Multiple-resource inventories (MRI) are data collection efforts designed specifically to meet all or part of the informational requirements for two or more functions or sectors (Lund 1986). They offer advantages over single-functional inventories in that MRI are more economical and provide more comparable data across the inventory unit.

Resource specialists have conducted multiple-resource inventories on forestlands and rangelands in the United States for some time (McClure et al. 1979). Foresters have also conducted multiple-resource inventories in Sudan (Lund et al. 1990), Tanzania (Mgeni 1990), and Australia (Vanclay 1990). Satellite-based imagery, global positioning systems, and geographic information systems have been used successfully in some of these efforts.

Holistic Needs

Not only are multiple-resource inventories needed, but today's decision-makers at the national and international level need holistic inventories of all lands and resources. This is especially true when we want to monitor changes in land use and productivity. There is too much interaction and interchange of uses between agriculture and forestlands, for example, to consider them in separate inventories or monitoring efforts. In the tropics, farmers are rapidly converting forestlands to agriculture. One way to reduce this is to improve yield from the agricultural lands. Thus, the decision-maker needs more information on existing agriculture lands. On the other hand, many of the agricultural lands in the temperate and boreal areas are being converted to forests. The decision-maker needs to know the capability of the agricultural lands to sustain given tree species.

In Sudan, for example, forestlands are defined the same as they are by FAO. However, the Sudanese foresters are equally interested in finding lands that once were forested but are no longer. These are lands where reforestation methods may be most successful. Similarly, at a recent ASEAN Seminar on Land Use Decisions (ASEAN 1992), member countries recommended the development of integrated land-use policies and examination of nonforestlands for conversion to forestlands to take pressures off natural areas. In order to carry out such recommendations, one must conduct integrated or multiple-resource inventories across all lands.

Global Connections

Because funds for such activities are limited, cooperation between national and international groups is essential if we are to get a complete picture of what is happening to the earth's limited resources and precarious environment.

If the most politically acceptable global monitoring is the aggregation or participatory method, nations must have guidance on how to design their monitoring efforts. If the single approach must be used, coordination and standardization among groups doing multicountry estimates are needed if we are to get a complete and understandable picture of the earth's resources.

At the endorsement of the Food and Agriculture Organization of the United Nations, the International Union of Forestry Research Organization (IUFRO) Working Party on Remote Sensing and World Forest Monitoring (S 4.02.05) is developing a set of Guidelines for World Forest Monitoring. The basic input for these guides was developed at the Wacharakitti International Workshop on Remote Sensing and Permanent Plot Techniques for World Forest Monitoring, sponsored by IUFRO S 4.02.05 and held in Pattaya, Thailand, January 13-17, 1992.

The objectives are to provide guidelines to yield internationally compatible data at the global level, to ensure effective use of funds through coordination and cooperation, and to promote accurate use and sensitive reporting of results.

The short-term goals are to outline the principles for data sharing for global forest resource statistics and to create data indices. The long-term goal is to set up a global network of forest resource managers to supply monitoring information.

The guides simply suggest that if a nation or group is going to collect forest information that nation or group should collect the data specified to the given standards or have the capability to convert the data to the standards and guides. Listed within the guides are minimum data requirements, land-cover classification schemes, and direction on use of remote sensing and establishment of sample plots.

The expected end product would be a network of databases, which when incorporated in its entirety will monitor forest resource estimates for the world. The final result of these guides will be a multinational network that will consistently provide reliable information to the international community.

Even with that system, there are some obstacles to overcome:

1. The standards and guides may not be known. This may be overcome by more publicity.

2. People may not see the benefits of using standards. Having local people help develop the guides and standards can build some ownership.

3. The timing for the monitoring effort may not meet local needs, or data collection costs may exceed available budgets. Forming partnerships and cost sharing may help overcome these obstacles.

RECOMMENDATIONS

Regardless of the method used for constructing global assessments, there are several things that one may do to improve estimates:

1. Statistically sample all lands for vegetation resources through permanent field plots. This network of plots will provide tools to help classify imagery, to evaluate the classification accuracy, and to yield data not available through remote sensing. This procedure will also help overcome land classification problems.

2. Record cover types according to an agreed upon vegetation-cover classification system, such as that by the United Nations Educational, Scientific and Cultural Organization (UNESCO 1973) for all lands. This will provide a common link to other monitoring efforts.

3. Record the coordinates of field plots and sample locations for use in GIS.

4. Collect and store basic data in a noninterpreted database. This will permit one to recompute estimates based upon a variety of classification or definition systems.

5. In any published report, state definitions and standards used and provide cross-references to international standards.

Our pool of existing information will increase as we expand our inventory and monitoring programs to include all resources in all lands. Our ability to access, use, manipulate, and analyze the resulting data will increase as we move toward global standards for data collection. As our global information base improves, we should become better able to manage the earth's resources.

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Integrating Satellite Imagery and GIS into Natural Resource Management

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Abstract

This paper demonstrates the utility of geographic information systems (GIS) and image processing as information tools in forest management. The application of GIS to address management issues of old-growth forest in the Pacific Northwest is used to assess the utility of GIS. Improvements in technology are considered, including improved resolution of the data from earth resources satellites. Computer hardware is becoming more cost-effective, and significant increases in operating speeds make interactive data processing much more responsive to management needs. Software is becoming more sophisticated and much more integrated so that vector and raster data sets are more easily used together. All of these improvements have made it possible to meet map accuracy standards and to identify sources and types of error occurring in thematic classification. This leads to three main types of use: (1) the combination of image data and GIS information to produce image maps, (2) the use of images from aircraft or satellites to update GIS information, and (3) the use of GIS data layers as ancillary information in image classification to increase accuracy and reliability. A variety of specific applications—including mapping and recording landscape characteristics using digital elevation models, updating maps, and identifying changes—is discussed. The present demand for these applications is seen as a small fraction of the future requirement for GIS information about land use and land management. Data capture and the generation of global data sets and management techniques are identified as issues of growing importance. These activities generate a growing need for training and support of GIS if the power of the technology is to be applied effectively to natural resources issues.

INTRODUCTION

As the world's population has grown, so have demands on forests and rangelands to provide multiple resources for diverse clientele groups. Rapid land-cover and land-use decisions are often made in the courtroom rather than on the ground. As a result, the management of wildlands has become increasingly complex, requiring sophisticated information-management tools and timely, detailed data.

This paper demonstrates the utility of geographic information systems (GIS) and image processing as information tools in forest management. The paper first discusses changes in the demand for information concerning wildland resources that invite the spatial analysis capabilities of GIS. Next, it presents advances in technology and education that have fostered the integrated use of GIS and image processing. The final portion of the paper discusses opportunities for integrating GIS with image processing to assist in resource management and planning. The paper concludes with a discussion of the status of GIS and remote sensing.

WHY GIS?

Over the last ten years, GIS has emerged as an extremely effective tool for prioritizing and analyzing resource-management alternatives. Geographic information systems provide a link between spatial data (x, y coordinates on maps) and attributes information that describes the spatial data (see Congalton and Green [1992] for a detailed explanation of the concepts of GIS). Because conflicts over land use are by definition spatial, a GIS provides a powerful tool for defining and focusing discussion of the advantages and disadvantages of alternative land-use allocations.

The controversy over old-growth management in the Pacific Northwest is a recent example of the use of GIS in forest management. In an effort to gain badly needed information regarding old-growth forestlands, the Forest Service built a GIS database for the national forests of Oregon and Washington. Not only did the database provide them with the ability to estimate and display locations of remaining areas of old growth but the GIS data set allows planners and decision-makers to answer questions such as

1. What is the average acreage of individual old-growth stands and how continuous or fragmented are they?

2. What tree species are found in existing old-growth stands? Which stands are ecologically diverse? Which are homogeneous?

3. How does a change in the definition of old growth affect estimates of the extent and amount?

The flexible design of the GIS gave analysts the ability to simulate the results of changes in management and policy before they were put into effect (Teply and Green 1991).

WHY GIS AND IMAGERY?

Every GIS has four components:

1. Computer software to enter, store, manipulate, analyze, and display the spatial data and their associated attributes

2. Computer hardware (e.g., plotters, central processing units, digitizing boards) needed to run the software

3. Data used as inputs for the analysis of alternative management decisions

4. People to operate the system

Increasing conflicts over land use have created a demand for immediate access to accurate information about land status and the spatial interrelationships of forest resources. While the costs of GIS software and hardware have dramatically decreased over the last decade, GIS data is still the most expensive component of a GIS, often comprising 60 to 90 percent of the total system cost. The need for inexpensive, accurate, and timely GIS data has created a collateral demand for digital imagery.

Historical failures associated with the use of digital imagery as a base for forestland mapping are abundant and well known (Meyer and Werth 1990). However, recent technological innovations have dramatically altered the methods available for forest mapping (Teply and Green 1991, Congalton et al. 1993). The integration of GIS and image processing into natural resources management directly results from five recent technological and organizational advances.

First, the imagery has improved. The minimum unit of area (pixel) sensed by the satellites has decreased in size, allowing for the derivation of much greater spatial detail. The imagery initially used to map forestlands, Landsat Multispectral Scanner (MSS) data, has a spatial resolution of only 80 meters. Satellite imagery presently available and fully integrated into forest mapping includes Landsat Thematic Mapper (TM) data (with a spatial resolution of 30 meters) and both multispectral and black and white SPOT data (with spatial resolution of 20 and 10 meters, respectively). In addition the types of electromagnetic energy sensed by the satellites (analogous to numbers of colors "seen") have also increased from four spectral bands in MSS data to seven bands (three visible and four infrared) in Landsat TM data. Numerous other sources of digital imagery are being investigated and integrated into forest mapping, including scanned aerial photography, airborne scanners, video, and radar (Lachowski et al. 1992).

Second, computer hardware has become more powerful and less expensive. With the advent of UNIX workstations and the increasing power of personal computers, processes that used to take two weeks to finish can now be completed in two hours, creating the ability for interactive processing and evaluation of image classification and increasing the accuracy at each step. In addition the decrease in the cost of peripherals, such as scanners and electrostatic plotters, allows the input and output of completely integrated image and GIS data.

Third, GIS and image-processing software has become fully integrated and more sophisticated. Only in the last four years has it become possible to reliably register satellite imagery and to link that registered image both visually and statistically in a computer software system. The integration makes possible the analysis of relationships between spatial location, spectral variation in the image, and land-cover variation on the ground.

Fourth, procedures for the assessment of map accuracy have been fully implemented and accepted as critical elements in the production of any GIS layer derived from remotely sensed data (Story and

Congalton 1986, Congalton and Green 1991). Past mapping efforts, including both photo interpretation and image processing, left map accuracy unassessed and unknown. The correctness of map data was usually judged by qualitative impressions that followed initial use of the map. The introduction of accuracy assessment procedures has resulted in the development of unbiased, quantitative measures of map accuracy. The measures make it possible (1) to set accuracy standards that must be met prior to the adoption of a GIS data layer and (2) to identify possible sources and types of confusion occurring in the layer.

Finally, training in GIS and image processing is now offered in mainstream university courses, resulting in professionals who understand computer concepts and the relationships between variation in vegetation and variation in spectral response. The people producing maps are now foresters, ecologists, wildlife biologists, etc., who have mastered not only their specific resource field but also the concepts of GIS and image processing.

The result of these advancements is the integration of image processing with GIS layers for resource mapping. Accompanying the integration is a decrease in the cost to produce traditional maps required for forest management, a decrease in the amount of time required to produce the GIS layers, an increase in the detail of information linked to the layers, and an increase in the variety of maps and outputs available from the GIS database.

OPPORTUNITIES FOR INTEGRATING GIS WITH IMAGERY FOR FOREST AND RANGE RESOURCE MANAGEMENT

Imagery can be integrated with GIS for forest management in three basic ways:

1. The imagery and GIS layers can be combined to produce image maps.

2. The imagery can be used to produce and update GIS coverages.

3. GIS layers can be used as ancillary information to increase the accuracy of image classification.

Image Maps

The simplest and perhaps most effective way to integrate GIS layers and imagery is in the production of image maps. In this technique, imagery is combined with map information to create a photo-like product that displays both imagery and map information. Image sources usually include satellite imagery or digital aerial photography. Image maps increase the utility of a map because the map information displayed includes an actual representation of the landscape.

Image maps greatly increase the amount of information available to field personnel by combining two key field tools, i.e., maps and photography. They can also (1) reduce the amount of time it takes to locate specific sites in the field; (2) increase the accuracy of delineation of areas that have changed since the image or that are anticipated to change (e.g., harvest units); and (3) allow a finer visualization of the distribution of land-cover variation across a mapped polygon. The increased information of an image map is particularly important to land managers interested in assessing or altering a specific area (e.g., a pocket of pest mortality or a group of snags) that is smaller than the minimum mapping unit. Image maps are also effective tools for conveying information in public meetings where a picture is literally worth a thousand words.

The key to image maps is the complete and accurate co-registration of the imagery to the GIS map layer. In the past, image registration was usually both difficult and inaccurate, often resulting in degradation of the data. New software developments (such as ERDAS's Ortho Digital Module) integrate photogrammetric techniques into image registration by performing an orthogonal rectification that incorporates terrain correction. The software advances have brought image maps into the hands of the forest or ecosystem manager.

GIS Coverages

Digital imagery can be effective primary information for (1) the production of GIS coverages of landscape characteristics, such as vegetation, land use, roads, and harvest units; (2) the creation of digital elevation models; and (3) the change in detection and updating of existing GIS coverages.

Landscape Characteristics

Aerial photography and satellite imagery are useful for the characterization of landscapes because variation in the photo or satellite image is usually highly correlated with variation in the landscape. Aerial photography has long been used to delineate and classify forest vegetation and land-use type. Turning classified and delineated photography into a GIS layer requires the transfer of the classification to a planimetric base, followed by the entering of the information into the computer by either digitizing or scanning. The four steps of classification, delineation, transfer, and data entry can be extremely time intensive.

Teply and Green (1991), Bernath et al. (1992), Gonzales et al. (1992), Miller et al. (1992), and others have shown that digital processing of satellite imagery, combined with field visits and the use of aerial photography as ancillary data, can accurately produce both detailed and broad GIS coverages of forest and range vegetation type. Four advantages of using satellite imagery versus aerial photography as the primary information base exist:

1. A substantial reduction in the time and cost to produce the GIS layers. For example, the abovementioned project to map old growth in the Pacific Northwest was completed in fourteen months, an effort that would have required several years using traditional photo interpretation techniques.

2. The production of a GIS layer much richer than that resulting from photo interpretation because the GIS layer can contain both traditional vegetation polygon labels and information about each spatial unit sensed by the satellite sensor (i.e., pixel).

3. The opportunity to perform interownership analyses, such as cumulative impacts, because the economies of scale in digital image processing are great, making it relatively inexpensive to map large expanses of land. Thus, mapping an entire region is feasible.

4. The fast and inexpensive updating of GIS coverages by directly comparing the satellite images used to create the coverages with those taken at a later date.

In addition to vegetation and land-use mapping, several national forests and industrial concerns are presently using SPOT 10-meter panchromatic data to map and create GIS coverages of roads and harvest units. Digital orthophotography can be used for the same purpose. Using this technique, roads or harvest units are digitized by the operator directly on the computer screen through "heads up" digitizing.

Satellite imagery is not suitable for every project. Those applications requiring a scale larger than 1:12,000, covering an area 5000 acres or smaller or requiring identification of resources that are smaller than the spatial resolution of the imagery will be better accomplished with large-scale aerial photography. Recent advances in orthocorrection software, however, make it possible to use scanned digital aerial photography in the production of GIS coverages.

Finally, GIS coverages derived from remotely sensed data (including both satellite imagery and aerial photography) will never supply or replace the detailed resource information that can only be captured through field investigations. A map of GIS coverage is a stratification of the variation in landscape characteristics. It can be used to model existing, past, and future conditions, to analyze possible management activities, and to allocate field samples; but it will never replace the field information required for site-specific management. Once site-specific information is gathered, however, the data can be entered into a GIS as an attribute of the site and thereby retained indefinitely for future reference.

Digital Elevation Models

Recent software developments have made it possible to use either stereo satellite imagery or stereo digital photographs to generate digital elevation models (DEMs). Digital elevation models are digital grids of points of known latitude, longitude, and elevation. The grids can be used to generate GIS coverages of topographic conditions such as slope, elevation, and aspect. While digital elevation models at a 1:250,000 scale are available for the entire United States from USGS, large scale DEMs are often difficult and expensive to obtain using traditional photogrammetric techniques. The new software greatly facilitates the creation of high-resolution DEMs for both small and large projects. Three-dimensional perspectives can be created from integrating digital elevation models with GIS coverages, satellite imagery, or digital orthophotos.

Change Detection and Updating

Change detection, the comparison of differences in the landscape over time, is easily and inexpensively accomplished through the overlay of two images that vary only by their dates. Image-to-image change detection is also superior to map-to-map comparisons because two maps of different dates often differ more because of differences in mapping techniques and/or classification systems than because of landscape changes.

However, image-to-image comparison requires the isolation and control of all factors causing differences over time. Thus, atmospheric and seasonal variation must be accounted for and the images to be compared must be precisely registered to one another.

The cost and time savings realized by image-to-image change detection also promote rapid updating of GIS databases to reflect changes in resource condition. Use of image-to-image comparisons to assess change and to update GIS coverages is growing. Lachowski et al. (1992) present an example of the use of image-to-image change detection to monitor forest-plan implementation. Similar techniques are also being adopted by regulatory agencies to assess the cumulative impacts of forest-management activities.

GIS Coverages as Ancillary Data

Classification of aerial photography for the creation of forest vegetation maps requires that the photo interpreter understand the relationship between forest vegetation type and the various colors, tones, and textures of the photo. The photo interpreter must also be knowledgeable of the location of each photo and the relationship of vegetation type to location, aspect, slope, and elevation. Finally, the photo interpreter will use all reliable existing information, including vegetation maps, inventory plots, stand examinations, and harvest and fire history to aid photo classification.

A satellite image contains qualities of color, tone, and texture similar to those found in aerial photography. Like photo interpreters, image processors also consider location when classifying an image by using GIS layers as ancillary data to increase the accuracy of information derived from satellite imagery. Thus, existing GIS layers are often used as aids in the production of new GIS layers.

GIS layers can be used as ancillary information in image classification in three basic ways:

1. As aids in locating areas of interest on the imagery. One of the most time-consuming tasks in image processing is determining precise locations on the imagery. GIS layers of photo flight lines, streams, existing vegetation classes, and/or roads overlaid on the image either on the computer screen or in maps provide direct links between locational or informational attributes and the image.

2. As coverages for stratifying the image prior to classification to control spectral variation. For example, GIS coverages of aspect and elevation can be used to cut the image into areas of broad ecological homogeneity (Green 1990).

3. As layers in post-classification modeling for quality control. Classification of conifer species is as difficult in image processing as it is in photo interpretation. Conifer species are often spectrally confused. However, because conifer species distribution is highly correlated with aspect and elevation, GIS coverages of aspect and elevation can be used to check for unallowable species occurrences. Classifications can also be directly compared to existing GIS coverages, and differences can be further investigated (Golden and Lackey 1992).

CONCLUSIONS

1. The present demand for integrating GIS with image processing into forest management is only a small fraction of what the demand will be in future years. Increasing conflicts over land use and land management will accelerate the demand for fast, accurate, and inexpensive information about the landscape.

2. Currently, users tap only a minimal amount of existing information in the imagery and in the relationships between GIS layers. Perhaps the largest gap in GIS is the relatively small amount of analysis performed. GIS has evolved through two steps and is presently entering a third. The first step required the acquisition of GIS hardware and software. Organizations committed large funds to the formidable tasks of acquiring a GIS system and training personnel to use the system. The second step involves capturing data into the GIS. Most of this paper has concentrated on new methods for capturing GIS data and for integrating the data into resource management. This step is not entirely complete, but universal data sets are becoming available, at least in the United States. The third step is the analysis of relationships in GIS data layers to help extract and identify some of the complex interrelationships that exist within forest and range landscapes. The third step will enable resource managers to test management assumptions through sensitivity analysis.

3. Increased training of personnel is critical to the application of these powerful information tools to resource-management problems. Only with competent analysis and capable managers can the benefits of the high-investment costs in GIS hardware, software, and data be fully realized.

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Forest Service Applications of Remote Sensing and the National Training Program

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Abstract

The USDA Forest Service uses various forms of remote sensing in resource-management activities. Geographic information systems (GIS) are used to manage data, including remotely sensed data, in forest plan development, ecological mapping, and similar tasks requiring spatial information. An overview of remote sensing tools used in the Forest Service includes aerial photographs, airborne video, satellite sensors, and positioning systems. Discussion of applications considers the periodic assessment of forestland and resource-management plans, using as an example Mark Twain National Forest in southern Missouri. Vegetation mapping and old-growth mapping are illustrated by an example from the Santa Fe National Forest. Airborne video tied to a GPS is used in the southwestern region for forest pest management. Remote sensing and GIS are seen as important tools for land management, including management of rangelands. An extensive training and awareness program is designed to broaden the awareness of remote sensing technologies, to upgrade and maintain skill levels of Forest Service employees, and to provide training for specific tasks, applications, and new techniques. The needs of today's resource managers call for more current and consistent information. Proper combination of technologies and training should provide for the collection and utilization of data for multiresource use in a cost-effective manner.

INTRODUCTION

The USDA Forest Service has been using various forms of remote sensing to assist in a variety of resource-management tasks. The Forest Service considers remote sensing to be an integral part of information management, providing input for forestwide databases. An important source of land-cover information, especially of the vegetation layer for geographic information systems (GIS), data layers obtained from remote sensing are used primarily in forest plan development, in implementation and monitoring, in ecological mapping, and in many other tasks requiring spatial information.

Remotely sensed data include aerial photographs, i.e., imagery from airborne and spaceborne devices, such as multispectral scanners and video cameras. Positioning systems, such as the global positioning system (GPS), are used in conjunction with remotely sensed imagery to assist in locating various features. Analysis and interpretation of remotely sensed data are done in a georeferenced framework, most often in a GIS environment. The GIS and image analysis is often used as a combined capability. This means that (1) remote sensing/image analysis is an important data source for GIS databases, (2) analysis requires access to layers stored in a GIS, and (3) results of analysis of remote sensing data are stored as new layers in the database.

REMOTE SENSING TOOLS USED IN THE FOREST SERVICE

Following is a short description of some—but not all—of the remote sensing tools being used by the Forest Service. The use of these tools is increasing throughout the agency.

Aerial Photographs

Aerial photographs have been in use in the Forest Service for over fifty years. They provide an important historical perspective of our forests and are indispensable for a variety of assessments and mapping tasks (Greer et al. 1990). Information from photographs can now be digitized directly into a GIS database with the use of an analytical stereoplotter (Bobbe and Hoppus 1992).

Airborne Video

Video has existed since the start of television. Recent applications from airborne platforms have provided a powerful tool for resource managers. A video camera can be mounted in a small airplane, and imagery can be viewed as soon as the flight is complete. Video imagery linked with GPS can provide locational information for each frame, allowing the user quickly to find specific areas on maps or images (Bobbe and Ishikawa 1991).

Satellite Scanners

The Forest Service currently uses data from two satellites—Landsat and SPOT—and is also making considerable use of AVHRR for fuel mapping over large areas and for forest mapping across the United States. Data from these satellites, once geocoded and terrain-corrected, can be used in a GIS in two forms. The first is to create an image backdrop for display with other layers; the second and more widely used is to classify digital data into land-cover classes and to store the results in raster and/or polygon format in a GIS. These layers can then be used for a variety of applications, such as modeling. Digital satellite imagery has been used for large area forest assessment, for detection of change (Sader 1988), and for statewide inventories (Winterberger and LaBau 1988).

Positioning Systems

The navigation and positioning systems are generally not considered to be remote sensing systems. However, they are very important tools for data collection. The global positioning system is a widely used satellite-based system that gives a location in terms of latitude, longitude, and elevation (Gerlach and Jasumback 1989). The accuracy of GPS ranges from "geodetic quality" (within centimeters of true location) to "resource quality" (within meters), depending on the quality of receivers and collection methods used. The system can be used to trace directly features on the ground, such as roads, trails, fire damage, and other point, line, or area features. This is done by placing a receiver antenna at an unknown location or by walking, driving, or flying along a road, trail, boundary, or other feature.

EXAMPLES OF APPLICATIONS OF REMOTE SENSING

The Forest Service has a number of field applications of remote sensing data (Bain 1991). In most of these applications, satellite data provide information on vegetation and other land-cover types and are incorporated into GIS (USDA Forest Service 1992a).

The following examples of applications of remote sensing illustrate a cross section of current requirements. Monitoring of forest plans, vegetation mapping and old-growth modeling, and vegetation mapping/monitoring on rangelands are a few of the areas in which spatial information and analysis have become important.

Monitoring Forest Plans

Forest Land and Resource Management Plans require periodic assessment of current conditions against what was defined in the plan's standards and guidelines. In Mark Twain National Forest, located in southern Missouri, two Landsat Thematic Mapper (TM) images (acquired in 1982 and 1989) were used to detect land-cover changes over the seven-year period and to compare them to the plan's standards and guidelines. The changes detected with Landsat were field verified (about 84 percent accuracy) and stored in a GIS. This, along with management areas and ownership boundaries, allowed the monitoring of selected standards and guidelines related to certain vegetation conditions. This process proved to be a very efficient and economical method of forest plan monitoring and acquiring data for GIS (Platt et al. 1992, Maus et al. 1992).

Vegetation Mapping and Old-Growth Modelling

The location and quantity of "old-growth" forests, in conjunction with threatened and endangered species, are very important management issues. The Southwestern Region used vegetation layers derived from Landsat TM and existing ecological data to model old growth on Santa Fe National Forest (Gonzales et al. 1992). The procedures are similar to those developed in the Pacific Northwest Region (Teply and Green 1990). Three vegetation-related layers were derived with the following accuracies:

1. Crown closure (four classes): 82% accuracy
2. Vegetation cover (nine classes): 77% accuracy
3. Tree size (five classes): 76% accuracy

These vegetation layers, along with other GIS data layers, have a multitude of applications for management of natural resources, old-growth mapping being just one of them. The derived vegetation information is current, is consistently and economically produced, and has a known accuracy.

Range Allotment Mapping/Monitoring

Remote sensing provides range managers with a way to extrapolate field sampling over large land areas, and GIS provides for spatial analysis and customized mapping of the stored data. The Southwestern Region utilized airborne video tied to GPS locational information to identify unique vegetation types for mapping with Landsat TM (USDA Forest Service 1992b). A video camera mounted in an aircraft and linked with GPS provided several hours of "ground" information at various swath widths (zoom factors) ranging from sixty to one thousand feet. This procedure was patterned after the technology developed by Forest Pest Management. The GPS locational information allowed the range conservationists to identify the video images on maps and on georeferenced Landsat imagery. A computer-assisted classification of Landsat imagery was done for several allotments. This provided range managers with current information in a digital format and focused their more costly field-data collection process on specific problem areas.

A combination of remote sensing and GIS provides important tools for range managers. Data derived from various remote sensing sources and stored in a GIS help to determine suitable and unsuitable lands for livestock grazing, to derive habitat types, and to identify potential range structural improvements and pasture-management alternatives.

TRAINING AND AWARENESS

The Forest Service has established an extensive training and awareness program in the applications of remote sensing. The objectives are to

1. Broaden the awareness of remote sensing technologies
2. Upgrade and maintain the skill level of Forest Service employees
3. Provide training for specific tasks, applications, and/or new techniques

Training and awareness programs are designed and delivered at various levels of the Forest Service organization through several outlets. Training is offered by Forest Service units, by universities, and through contractual agreements.

The primary Forest Service organization responsible for training in remote sensing is the Nationwide Forestry Applications Program (NFAP) located in Salt Lake City. NFAP develops and conducts training in cooperation with regional and experiment station training coordinators. The initial emphasis was on utilization of aerial photographs, the most commonly used remote sensing tool. During the past few years, the emphasis has been broadened to include airborne videography, global positioning system, digital image analysis, and integration of remote sensing into GIS. These requirements are growing as new technologies become available.

A typical training session lasts three to five days and is conducted at a national forest, in a regional office, or at another location convenient to attendees. This proximity minimizes the cost of travel and also gives an opportunity to include a field exercise, a very important part of training. Training materials are usually tailored to the specific needs of the group.

The Forest Service's entry into the digital GIS world increases training needs. Many resource managers need to be aware of the new technologies that will assist in their jobs. Others need to learn new skills in order to fit into the evolving Forest Service organization.

The needs of today's resource managers call for more current and consistent information, ranging from small stands to entire national forests, including adjacent non-Forest Service lands. There are many tools, such as remote sensing and GIS, available to forest-resource managers. Proper combination of technologies and training should enable the collection and utilization of data for multiresource use in a cost-effective manner.

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Gap Analysis: A Geographic Approach for Assessing National Biological Diversity

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Abstract

The global concern with reduction in biodiversity has generated responses in the United States, such as the Endangered Species Act (ESA). Although the ESA has had some effect, the species-by-species approach presents a problem because it does not consider the broad ecological principles of biodiversity including the need for balance between different species and their combined influence on a given habitat. There is an implicit assumption that national parks, wildlife sanctuaries, and other protected areas provide for conservation needs. However, these areas have not necessarily been delineated on the basis of animal habitat zones or ecologically significant units. Gap Analysis is an evaluation method providing a systematic approach for assessing the protection afforded biodiversity in a given area. It uses geographic information systems to identify "gaps" in biodiversity protection that may be filled by the establishment of new preserves or changes in land-use practices. Gap Analysis has three primary layers: (1) distribution of vegetation types delineated from satellite imagery, (2) land ownership, and (3) distribution of terrestrial vertebrates as predicted from vegetation cover using habitat preference models. Vegetation classification procedures using satellite image or aerial photograph analysis are linked to wildlife / habitat databases. Gap Analysis includes seral as well as climax vegetation, and classes must be compatible with those used in neighboring states. The examples of these procedures for the Utah Gap Analysis are given with some reference to Gap Analysis in other states. The overall approach provides a logical base for evaluating and protecting national biological diversity.

INTRODUCTION

The rapid loss of biodiversity remains mankind's greatest threat. Traditionally, approaches to stem this loss have concentrated at the species level and are brought to bear only when a species is brought to the edge of extirpation or extinction. Within the United States, the primary means of stemming this loss is the Endangered Species Act (ESA). Recent reports have criticized the ESA for several reasons, including a backlog of unaddressed listing petitions, a failure to develop and implement recovery plans in a timely fashion, and a lack of adequate funding to meet objectives (GAO 1992). A primary cause of these problems is that the act focuses on individual species. Effort expended on this species-by-species approach is inefficient, expensive, and biased toward "charismatic megafauna" having broad public appeal (Pitelka 1981, Hutto et al. 1987, Scott et al. 1987, Noss 1991). Last ditch efforts also lead to economic conflict because they fail to provide a reasonable planning framework for economic interests.

Maintenance of biodiversity is the concept around which new concerns about biological conservation are centered. Definitions of biodiversity vary but generally include recognition of diversity at genetic, species, and ecosystem levels (Wilson 1988). Calls for the maintenance of biodiversity are an explicit recognition that biological loss occurs at all levels and that attempts to maintain this diversity-conservation effort must be applied to all levels, not just to endangered species (Noss 1991, Scott et al. 1991).

Historically, most national parks and other areas that implicitly are thought to protect biodiversity are selected for reasons other than biological. Although a variety of conservation methods for evaluating the conservation worth of areas has been suggested, few have attempted to provide a cost-effective means for evaluating biodiversity at the scale of the ecoregion. Here we describe a rapid conservation evaluation method for assessing the current status of biodiversity at large spatial scales. Called Gap Analysis, this evaluation method provides a systematic approach for evaluating the protection afforded biodiversity in given areas. It uses geographic information systems (GIS) to identify "gaps" in biodiversity protection that may be filled by the establishment of new preserves or changes in land-use practices (Scott et al. 1993).

Gap Analysis consists of three primary data layers. These are (1) the distribution of actual vegetation types delineated from satellite imagery, (2) land ownership, and (3) distributions of terrestrial vertebrates as predicted from the distribution of vegetation. Within the GIS, overlays of animal distribution and ownership can be used to estimate the relative amount of protection afforded vertebrate animals. Gap Analysis functions as a first-pass approach for organizing biological information. Depending on the nature of the issue, the database can be used to springboard into other, more detailed studies and is meant to be used as a proactive rather than reactive management tool.

VEGETATION CLASSIFICATION AND MAPPING

Numerous vegetation classification systems exist and are used in the United States, e.g., UNESCO, (Driscoll et al. 1984; Brown et al. 1980; Kuchler 1964). Classification schemes represent attempts to group vegetation into classes based on factors such as structure, taxonomy, or evolutionary history. Vegetation acts as an indicator of the physical and biological attributes of an area and has been used as a surrogate for ecosystems in conservation evaluations (Specht 1975, Austin 1991). Mapping of vegetation is a reflection of physical and biological attributes of a site and is the basis for most management.

Methods of mapping vegetation vary (Kuchler and Zonneveld 1988), and selection of a specific mapping method is largely goal-specific. Although several different mapping methods have been tried for Gap Analysis, all methods shared the following properties: (1) vegetation classes must be discriminated from satellite imagery or aerial photographs; (2) mapped classes must be linked with existing wildlife/habitat-relation databases; (3) classes must encompass seral as well as climax vegetation; and (4) classes developed in one state must be complementary with neighboring states (Scott et al. 1993).

Vegetation maps used in Gap Analysis quantify the extent, representation, and distribution of vegetation classes in the study area. Further uses of the map may include analyses of the amount and extent of fragmentation, identification of linkages and corridors (Noss 1991) between management areas, and use as a modeling tool for projecting probable pathways of future vegetation. Because the goal of Gap Analysis is to assess the current status of vegetation, plant-indicator species are used to identify the habitat type, usually at the series level (Driscoll et al. 1984). A national, hierarchically based classification scheme has been developed for the Western states (Bougeron et al. 1992) and is being expanded for the remainder of the United States. The need for a consistent classification scheme cannot be overemphasized; failure to develop such a scheme limits the ability of Gap Analysis to resolve biodiversity conflicts at large spatial scales.

A pilot project in Idaho synthesized a vegetation map from existing local, regional, and state vegetation maps. Based on lessons learned, a second project in Oregon added visual photo-interpretation of satellite imagery to locate boundaries of vegetation classes. Later, states such as California, Utah, and Nevada began mapping vegetation by a combination of digital classification of satellite data, visual photo-interpretation of satellite imagery, and reference to existing maps and other ancillary data. This approach has become the standard for all subsequent programs (Scott et al. 1993).

Vegetation mapping in Utah relied heavily on digital analysis of satellite data (Ramsey et al. 1992). Ancillary data used to model vegetation in Utah included digital elevation data, hydrology, an existing vegetation map, and training points collected from a variety of outside collaborators. From this a total of twenty-four cover types and three land-use types were mapped (Table 1). Based on preliminary data, map accuracy for Utah was estimated at 76 percent.

LAND OWNERSHIP

Land ownership categories are based on private and public lands. On public lands, knowledge of the administering agency is important because of different mandates and policies. The administering agency provides a strong clue to the kinds of management activities likely to occur on the land and their resultant effect on biodiversity. For example, Forest Service lands are managed under a multiple-use scenario that allows for a wide range of activities ranging from resource extraction to wilderness areas. Private lands, with few exceptions, are not managed for the preservation of native species but for human activity and needs, e.g., agriculture.

To obtain an estimate of the protection afforded biodiversity on the wide spectrum of ownerships, land ownership was assigned one of four management status classes (Scott et al. 1993). Class 1 includes areas with active management plans that, through management, maintain or mimic natural disturbances. Most national parks, Nature Conservancy preserves, and some U.S. Fish and Wildlife refuges are included in this class. Management Status 2 areas are generally managed for natural values but receive use that may degrade the quality of natural communities. This class includes most wilderness areas. Most nondesignated public lands, including USDA Forest Service, Bureau of Land Management, and state parklands, fall into Class 3. These are multiple-use lands. Class 4, private or public lands without permanent conservation easements, are managed principally for human activity. Urban, residential, and agricultural lands are included in this class.

WILDLIFE-HABITAT RELATIONS MODELLING

Biologists have long used knowledge of an animal's habitat to predict its presence or absence. Traditional approaches to mapping animal distribution include (1) dot distribution maps; (2) grid-based maps; (3) hybrid dot distribution and range maps; and (4) range maps (Scott et al. 1993). These methods rely only on the location or observation of specimens and include no information on the ecological conditions, e.g., vegetation, that favor presence of the animal. Using vegetation as a surrogate to map presence or absence of animals has limitations but also provides enhancement over traditional mapping. Because the process does not rely only on known locality records, unsampled areas can be included in predicted models. Coupling known locations with those predicted from vegetation can lead to exceedingly refined maps of species distribution. Given sufficient samples, the distributions can be mapped as a series of probability estimates.

Several factors complicate the use of vegetation to predict species presence and absence (Scott et al. 1993). Birds, for example, respond more to vegetation structure than to floristics (Miller 1951, Cody 1985). Because Gap Analysis vegetation mapping relies principally on floristics rather than structure, bird distribution maps may contain error. Gap Analysis assumes that this error is reduced by defining vegetation classes with the structural characteristics necessary to the bird.

A second complicating issue is differences in habitat breadth. Some species, like coyotes (*Canis latrans*), are generalists in their habitat. Others are restricted to a single habitat type. If an animal is associated with a single type and that type can be mapped, Gap Analysis provides an excellent predictor of range. If the type cannot be mapped or is contained in another class, predicted range can be far from actual. Moreover, our ability to map habitat classes often exceeds the natural history information available for a species. For example, Holland (1986) recognizes 375 plant communities in California. Many of the vegetation units differ only in the ratio of dominant to associate plant species. Although of interest to botanists, these differences may or may not be of importance to animals. Thus, Mayer and Laudenslayer (1988) cross-walked the 375 plant communities into fifty-three wildlife-habitat classes.

Although the number of plant communities can be high, natural history data linking animals to specific

Table 1. Cover types and descriptions identified in the Utah vegetation base map. Description refers to series; cover type can be a compilation of >1 series.

Cover Type	Description
Alpine	Grass-*carex*; grass-forb-low shrub
Subalpine	
Spruce-fir	Engelmann spruce; subalpine fir
Lodgepole pine	Lodgepole pine
Montane lodgepole pine	Lodgepole pine; Douglas fir
Lodgepole pine woodlands	Lodgepole pine; subalpine fir; aspen; sagebrush
Montane fir	Douglas fir
Ponderosa pine	Ponderosa pine; Douglas fir; lodgepole pine; sagebrush; grass
Aspen	Aspen
Limber pine	Limber pine; bitterbrush
Bristlecone pine	Bristlecone pine
Pinyon-juniper	Pinyon pine; juniper; sagebrush; grass
Mountain brush	Maple; oakbrush; serviceberry; snowbrush; bitterbrush; mahogany
Tall sage	Sagebrush
Tall sage with trees	Sagebrush; all pines; all true firs; Douglas fir; aspen
Low sage with trees	Sagebrush; pinyon pine; juniper
Salt desert shrub	Shadscale; *Atriplex*; greasewood; grass; winterfat; saltgrass; horsebrush; pickleweed
Creosote-bursage	Creosote brush; bursage
Blackbrush	Blackbrush
Grassland	Grass
Marsh	Cattail
Canyon shrub riparian	Birch; alder
Cottonwood riparian	Cottonwood
Willow riparian	Willow
Mountain forb	Groundsel; mulesears; bluebell
Agriculture	
Urban-industrial	
Sand dunes	
Barren	
Open water	
Streams-rivers	

communities are sparse for most species, requiring that mapped habitats be grouped into categories that correspond to the known information about a species. For example, the best information on a bird species may be that it is associated with coniferous forests. Given that at least seven mapped classes in Utah contain conifers, the potential distribution for that species is exceedingly general.

Data on natural history of plants and animals are collected in a variety of formats of which the state natural heritage programs are the best example. These databases, called Vertebrate Characterization Abstracts (VCA), contain state-specific information on the ecological relationships of every vertebrate species in the state. Unfortunately, information in the database is often fragmentary and may reflect particular interests of the state program rather than a more systematic approach to a database. In contrast Utah has a more detailed data set based on the Multi-State Fish and Wildlife Information Systems (MSFWIS) database. Although similar in concept to VCAs, the MSFWIS contains more tabular information better suited to geographic distributions (Table 2).

Linking known ecological relationships with the vegetation map provides a spatial component to range mapping. Within Gap Analysis, two sets of information are needed to model animal distributions. These are the digital vegetation map and the wildlife-habitat association data linking particular species to mapped vegetation classes. This simple linkage provides a description of the predicted spatial location for each animal species in the database. Once identified the maps go through an additional screening to further refine the predicted distribution. This involves comparing the predicted distribution to more refined spatial data. One such source of information is county-of-occurrence maps, a frequently available data source, especially for birds.

Predicted distributions fail for several reasons. Reptiles, for example, are poorly predicted by vegetation (Scott et al. 1993), probably because reptiles respond more to climate than vegetation per se. Second, species associated with hydrologic regimes are grossly overestimated unless hydrology is incorporated as a linear string. Fossorial rodents, such as pocket gophers and ground squirrels, are also overestimated, presumably because Gap Analysis vegetation maps do not integrate soil characteristics very well. Last, rare species having localized distributions are also overestimated. Nonetheless, species range predictions from Gap Analysis exceed the resolution of existing range maps.

DISCUSSION

Gap Analysis is a method of identifying gaps in the protection of biodiversity at state, regional, and national scales. Although designed to identify "gaps" in the protective network, the data collected for Gap Analysis can serve numerous other purposes. In one sense, the data represent the first systematic compilation of data on biodiversity that transcends political boundaries. As such, the data are a useful starting point for other efforts designed to protect biodiversity. Some important applications include the ability to note temporal and spatial change in the extent and distribution of vegetation types. When coupled with information on other "stressors" such as air pollution or urban development (Noss 1990), Gap Analysis data layers can provide a stable planning and forecasting environment for assessing impacts of man-induced change.

The magnitude of the databases generated for Gap Analysis also underscores the need for greater cooperation among different management agencies. The databases are large, require trained personnel to manage, and no single agency or group can continue to update the information in the databases without cooperation from others. Moreover, given the cost of developing the database (approximately $300,000 per state), it would be a waste of limited conservation dollars to duplicate the database in all agencies. Ideally, agencies with different mandates would springboard from the base Gap Analysis data layers and refine the data to meet their specific needs.

Gap Analysis originated from the idea that a species-by-species approach to the loss of biodiversity is neither effective nor efficient. It ignores the principal reason for the loss of biodiversity, i.e., the continual loss and fragmentation of natural landscapes. Ideally, Gap Analysis data could provide a framework in which sound conservation planning could be developed and implemented. This planning will require, at an early stage, consideration of a nationwide network of core biodiversity management areas (Noss 1987). Sustainable human uses would occur in other wildlands that serve to buffer and link core biodiversity areas (Scott et al. 1990). The accelerating loss of biodiversity places great premium on approaches like Gap Analysis. These approaches provide a logical basis for evaluating and, ultimately, protecting national biological diversity.

Table 2. Data fields for the Utah Wildlife Information Network. Detailed descriptions for each data field can be obtained from the Division of Wildlife Resources, Salt Lake City, Utah.

Taxonomy

- Group
- Common name(s)
- Scientific nomenclature
- Authority

County Level Distribution

- Historical
- Resident
- Nonresident
- Seasonal
- Distribution (%)
- Abundance
- Population
- Harvest

Administrative Units

- USFWS-refuges
- NPS-units
- BLM-units
- USFS-units
- State-WMAs
- Latilong data

Ecological Baseline

- Habitat associations
- Forest associations
- Animal/plant associations
- Environmental requirements
- Habitat suitability information
- Guilding information

Food Habits

- Trophic information
- General food habits
- Important food habits
- Information by life stage

Status

- Legal
- Biological
- Economical
- Ecological

Site-specific Data

- Latitude-longitude
- USGS quadrangle
- Township/range/section
- River reach
- River mile
- Other (e.g., UTM)

National Map Standards

- OWDC hydrologic units
- USFS ecoregions
- Potential natural vegetation
- Land use/land cover
- National wetland inventory

Life History Information

- Nesting/denning/spawning
- Gestation/incubation
- Clutch/litter
- Territoriality/dispersion
- Mortality/turnover rate
- Limiting factors

Management Practices

- Adverse management practices
- Beneficial management practices
- Existing management practices

References

- Literature base
- Species expert-credit

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The Position of GPS in Wildlife and Habitat Mapping

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Abstract

Global positioning system (GPS) technology is being implemented by the Department of Defense and is becoming generally available. Portable, lightweight, low-cost receivers give a rapid readout of location to within 100 feet in a few seconds. The geometry of the satellite GPS system and of the ground-based Long Range Navigation (LORAN) system is described. Examples are given of the use of the LORAN system to track black bears in the Spanish Fork area of Utah, using radio collars. This use provides an effective method of monitoring habitat usage and seasonal activity patterns. GPS is effective in field mapping because it provides navigation control for transects, permits precise recovery of study sites, and permits verification of habitat maps. A habitat study of Gambel's quail in southwest Utah provides a good example of this application. GPS is also used to provide control for the rectification of photogrammetric information, greatly increasing the efficiency and cost-effectiveness of aerial survey. Examples of Hopi rattlesnake and Gila monster studies in southern Utah are presented, illustrating the use of GPS to link field studies to studies of earth-resources satellite data. Combining these in a GIS environment saves countless hours of time, reaps large dividends in dollars, and proves to be an effective tool in managing natural resources.

INTRODUCTION

Global positioning system (GPS) technology is making major changes in the way information is gathered for mapping purposes. With rapid storage, automated retrieval, and high accuracy, GPS is making revolutionary changes in traditional field surveying and data acquisition. Geographic information system (GIS) technology combined with GPS data collected in field studies can be rapidly manipulated to model past, present, and future conditions for various management purposes. Wildlife and habitat information is also being affected by GPS usage. Using GPS is now faster and less expensive for data gathering and implementation into GIS coverages for wildlife information and management purposes.

This paper will attempt to give a brief overview of GPS and a few of the present and potential uses of this Star Wars technology in wildlife and habitat mapping and management.

OVERVIEW OF GPS

The U.S. Department of Defense (DoD) developed GPS technology to assist in military navigation and national defense. With the development of low cost and lightweight receivers, GPS technology is now available for use by virtually anyone.

As seen in Figure 1, the GPS system consists of three components (Hurn 1989, GPS Report 1992).

SPACE COMPONENT

The space component, when complete, will consist of a constellation of twenty-one active and three reserve satellites positioned approximately 12,600 miles above the earth. The satellites will be organized in six different orbital paths that will give any point on the earth a clear view of at least four satellites twenty-four hours a day. Each satellite has a unique code for identification by GPS receivers.

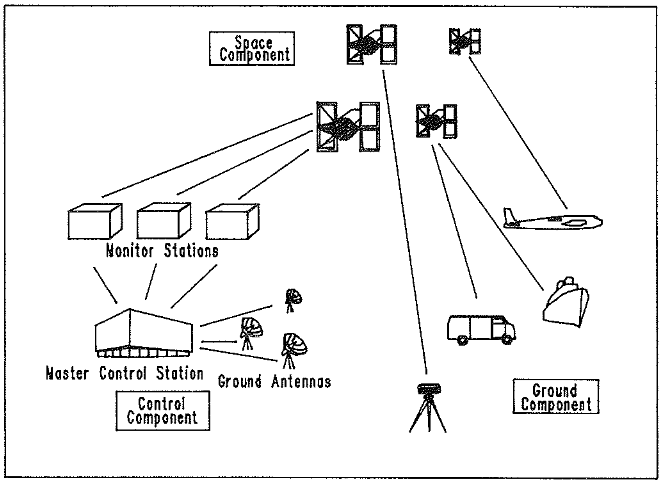

Figure 1. GPS configuration (GPS Report 1992)

Control Component

The control component consists of a master control station in Colorado Springs, Colorado, a group of monitor control stations, and upload antennae. The monitor control stations track satellites continuously and feed the recorded information back to the master control station. Using this information, the master control station calculates precise orbital information for each satellite and sends this information to the upload antennae. This information is then relayed to the satellites daily for corrections.

User Component

The user component consists of the various land, sea, and air receivers that allow reception of precise location, velocity, and time information.

GPS is based on the principle of triangulating a position on earth by measuring its distance to a grouping of satellites. If, as seen in Figure 2a, a position is X number of miles from satellite one, it is somewhere on an imaginary circle with a radius of X miles and centered on the satellite. If the position is Y number of miles from satellite two, it is somewhere on the circle where the spheres from the two satellites intersect (Figure 2b). By using a third satellite, only two points in space can be true for the position since the intersection of that satellite's sphere, with the two others, gives only two possibilities (Figure 2c). Since one of these possible locations is usually distorted in time or space, it is discarded by the processor in the GPS; and the correct position is displayed on the screen. A fourth satellite also solves the problem for the exact position and can serve to measure the elevation of the receiver.

As with most systems, there are limitations and errors that exist in GPS technology. Factors such as signal integrity, signal accuracy, satellite ephemeris error, and atmospheric refraction errors are handled by GPS hardware and software. One that is handled by the user is GPS signal reception. GPS requires direct reception of signals from satellites. Satellite signals travel in straight lines and cannot penetrate water, soil, or other solid objects. This means that anything that would block a line of sight could also block satellite signals. GPS, therefore, cannot function under water, underground, under heavy vegetative canopy, or under similar situations.

WILDLIFE AND HABITAT MAPPING

Mapping Wildlife

In managing wildlife, it is necessary to know where individual species or groupings of species are located. Various methods have been developed and used for study of individuals or populations of species. The most primitive method of recording this information has been to observe the species and then locate and record the site on hard-copy maps. For many situations, this has been adequate but has presented the problem of tracking locations of multiple species on a single map with the confusion created by the thousands of sightings collected or the management of multiple maps for the same area.

The other problem introduced is that of the mapping accuracy of the individual sighting or population parameter. The national map accuracy standard of a U.S. Geological Survey 1:24,000 quadrangle is

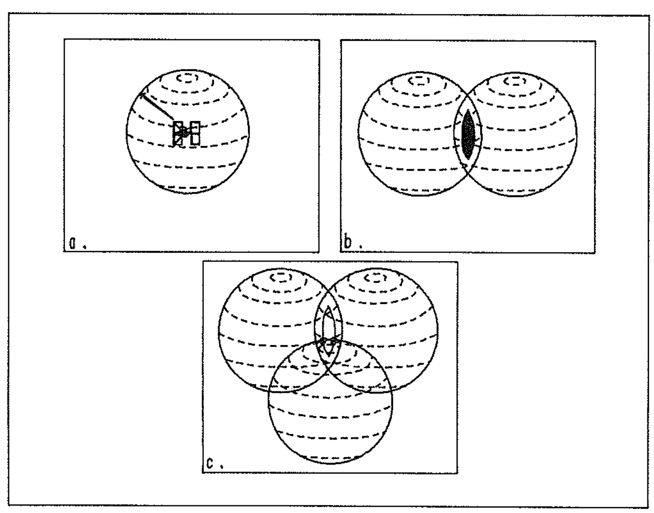

Figure 2. GPS triangulation (Hurn 1989)

approximately 40 feet. The width of the section lines on a standard quadrangle is approximately 40 feet also. Any drawing by the user on the map with a line width of that size introduces that amount of error. Greater line widths introduce greater error; that is, if the width of the line drawn by the mapper is twice the width of the section line, the introduced error is a minimum of plus or minus 80 feet but could be much more, assuming the base map had a 40-foot map accuracy error. Additional error is created in the automation of that information by digitizing.

By using precise time and distance measurements, GPS can accurately position to within 100 feet. By using a GPS base station receiver positioned at a surveyed location, the readings can be corrected based on differential averaging to within 6 to 45 feet (Kruczynski 1990). For most situations in wildlife and habitat delineation, these accuracies exceed accuracies obtained by commonly used mapping conventions.

Mapping wildlife presents many situations in which GPS can be of extreme value. Wildlife sightings and observations can be located immediately and more accurately. Export of location information to a GIS format takes place in automated modes, eliminating human error in transcribing, typing, or digitizing. Sightings and observations in GIS files become valuable sources of data for managing individual species and also for delineating the habitat in which the species is found. This is particularly important in regard to threatened, endangered, or sensitive species. In many cases, the sighting of one species indicates the possible presence of other associated species in the area.

The location of critical feeding, breeding, or resting areas can be enhanced by the use of GPS. For years the use of telemetry has been an important tool in the tracking of species and identification of important habitats. By placing a microtransmitter on a study animal, its movements can be observed in a general manner. A directional antenna is used to receive the signal from the transmitter. When the signal is located, a compass bearing is taken and plotted to give the direction of the animal from the antenna. By using two antennae, the intersection of the compass bearings would be the approximate location of the animal (Koeln and Cook 1984). Airborne antennae simply circle a continual reading to take a general triangulation.

The use of Long Range Navigation (LORAN) has made this process simpler. LORAN is a ground-based navigation system that emits radio signals within groupings of stations or chains. The Western United States coastal chain is seen in Figure 3.

By triangulating the receiver position in the chain, general locations can be obtained for navigation purposes. This method has been used in wildlife mapping for quite some time with generally good results. Various sources of error exist in the system, but probably the most significant in wildlife uses is known as "secondary phase lag." Since the signal transmission is in a straight line and the surface of the earth is curved, anything that is not in line of sight will suffer a delay in signal reception as shown in Figure 4. Additional delay may occur due to absorption of the signal by the surface of the earth.

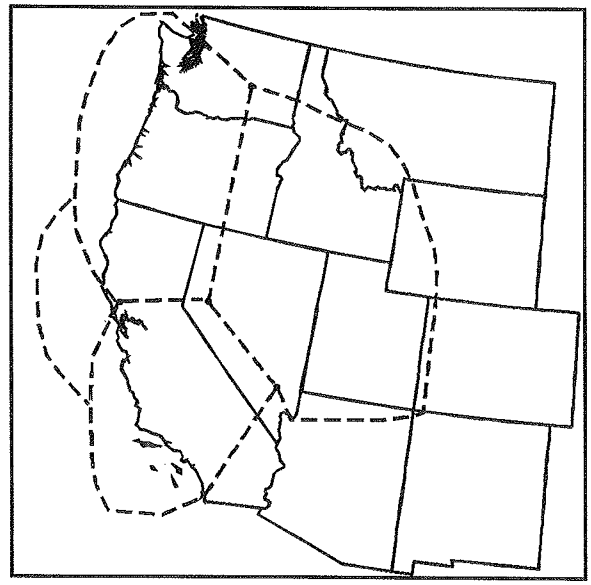

Figure 3. Western U.S. coastal LORAN chain (MIECO 1987)

On ground-based telemetry, this may be negligible except in areas of high relief where the reading can become extremely skewed (Lachapelle and Townsend 1991). With receivers in automobiles, boats, or aircraft, this becomes critical. Because of the time delay in signal reception, the point at which the signal is recorded may be as much as a few seconds from where the signal is received and updated. If the phase lag is extremely long, the position displayed on the readout can be many seconds old. The old readout coupled with the speed of travel could amount to a significant distance from the desired position, introducing a large error. In multichannel GPS receivers, the update rate of signal reception is no longer than one second, giving precise location information.

An example of telemetry in Utah is the tracking of black bears (*Ursus americanus*) for seasonal movements and location of winter den sites. By triangulating the microtransmitter signals with LORAN, a general area can be identified for the den site. Surveys must then be conducted on the ground to find specific locations, such as dens. LORAN is capable of locational accuracies of about 500 feet (Lachapelle and Townsend 1991, Langley 1992). Thus, a survey area of 250,000 square feet or 5.75 acres would be the result. With uncorrected 100-foot GPS readings, the

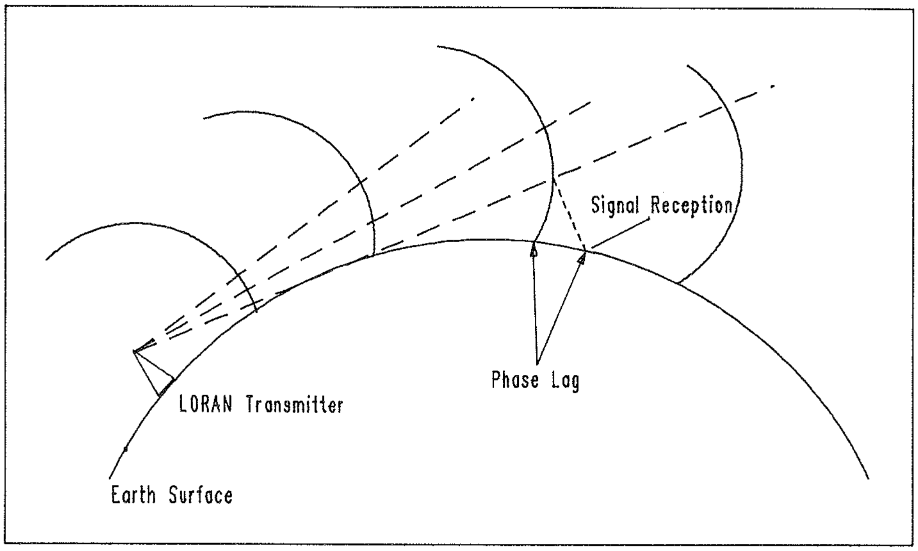

Figure 4. Secondary phase lag (Lachapelle and Townsend 1991)

area would be 10,000 square feet or .23 acres. By placing a receiver on the animal and relaying the location to another receiver, the movements of the study animal can be tracked (Figure 5) and could even be displayed interactively on a computer monitor. The possibilities of monitoring animal movements from on site or remote locations and mapping habitat usage by seasonal, daily, or even time of day are endless. Even the speed of movement could be measured.

The U.S. National Park Service conducted a study of desert tortoises (*Gopherus agassizii*) in the Joshua Tree National Monument in California. The objectives were to locate individual animals and den sites within the tortoises' habitat and to be able to return to the dens at later dates with high accuracy to monitor population and habitat trends. The area of the study was large, and two study alternatives were available. The first was to mark off a study grid with stakes and string so that precise locations could be defined. Each section of the grid would be 100 square meters, and the whole area would take 10,000 stakes. Such a grid was time prohibitive from the outset. The second alternative was to attach GPS receivers to individual tortoises and to monitor movements to locate den sites. Once dens were located, they were flagged and GPS readings were averaged to give precise locations. The results of the study were exciting in that individual tortoises and dens were easily located, the information was automated into a GIS, and an intensive, automated database was developed. For each tortoise, locations were entered

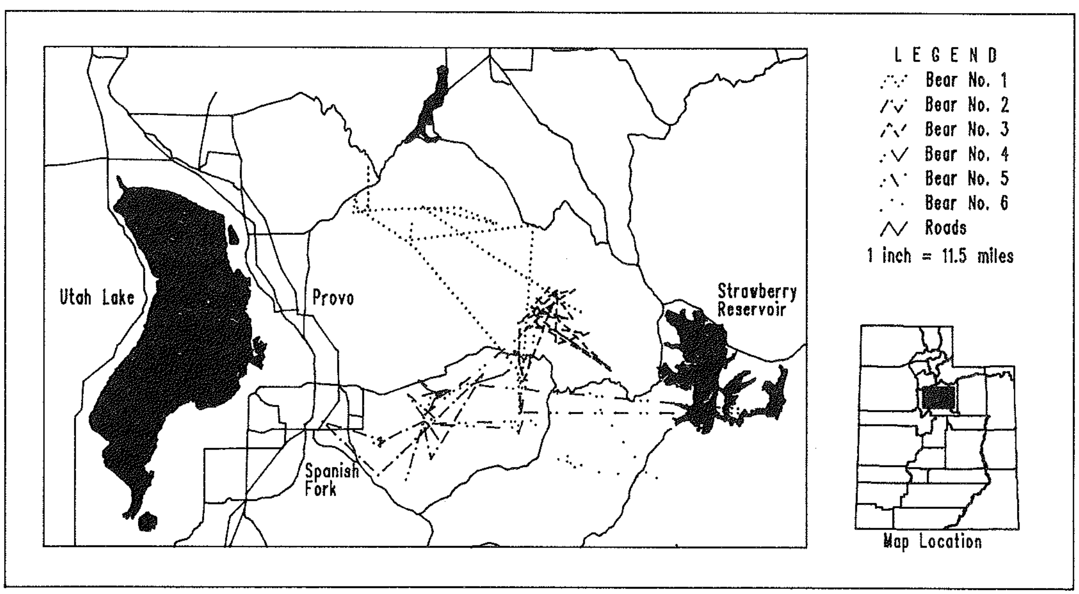

Figure 5. Bear locations from transmitter signals

describing size, weight, sex, and den information. Additionally, a color image of the tortoise was scanned and stored in a display facility that could be displayed on demand (Freilich and Moon 1991).

New advances in software are allowing the collection and automation of location attributes in the field. By attaching a personal computer to the GPS unit in the field, attributes can be entered "on the fly" as locations are taken. The use of personal computers means that forms for data collection can be automated and field data entered into GIS format as it is collected in the field. Additionally, information from other monitoring equipment, such as water, air, and soil gauges, can be automated directly from the sensor to the GIS with accurate location information, virtually eliminating the need for costly data transcription.

traverses by providing quality-control checks. When returning to the field study site, there is no traverse needed to get from control points to project sites, thus reducing traverse distances in the field. GPS also provides a means of controlling geodetic distortions in large field traverses. With conventional surveying, in order to compute the desired coordinates, the surveyor must transform field work from the surface of the earth to the ellipsoid and then transform again to the coordinate system. GPS gives the surveyed data measured in the ellipsoid. The surveyor need only translate data in one step to the coordinate system desired (Wurz 1991).

Delineation of wildlife distributions can be improved using GPS to spatially locate environmental parameters. Many species are mapped based on where they have been seen and where there is suit-

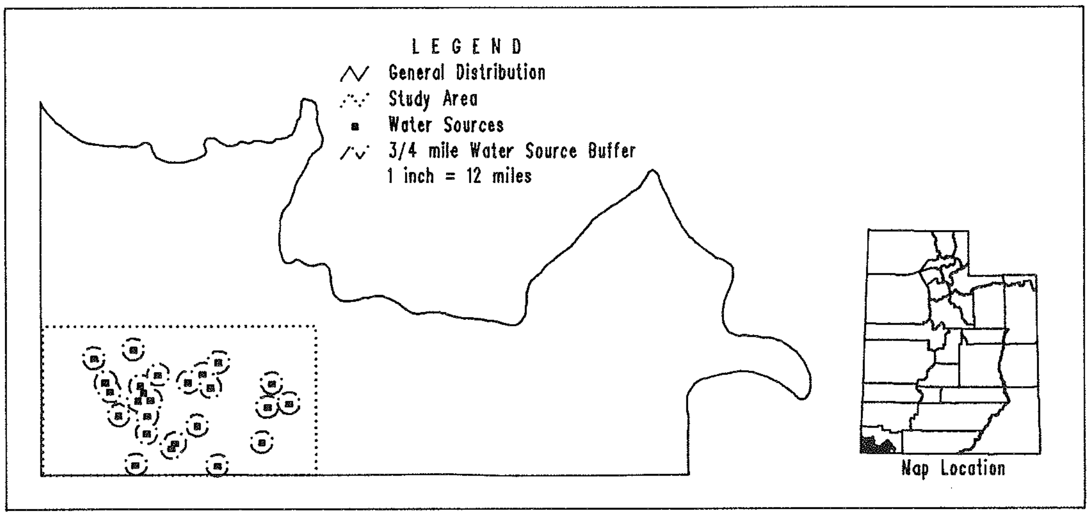

Figure 6. Gambel's quail model

Mapping Habitat

Field mapping of habitat types, timber stands, land ownership boundaries, or other areas is easily facilitated via GPS. The technology provides automated recording of field coordinates, traverse completion times, and a means of calculating areas. In addition the data are easily downloaded into GIS-ready files. In all surveys, the time interval of location recording can be varied to accommodate the speed of travel; that is, locations could be recorded every ten to fifteen seconds for surveys on foot and every second for aerial surveys, depending on the location accuracy desired.

The use of GPS offers an inexpensive way to traverse descriptions of metes and bounds on the ground, as well as to locate easements, waterways, water sources, structures, and other items.

In many situations, GPS aids in field-study able habitat. This use of GPS, however, may be too broad for many species since there are conditions that may keep them from using the entire habitat. Gambel's quail (*Callipepla gambelii*) is a good example. A study in southwest Utah (Nish 1964) showed that although good habitat, such as cover, forage, and terrain, was available throughout most of the study area over two-thirds of the birds studied were found within one-half mile of water sources. These sources existed in the form of springs, streams, cattle troughs, and guzzlers (man-made catchments provided for wildlife water sources). By taking GPS readings at these water sources and buffering the locations to appropriate distances in a GIS, wildlife distributions can be further refined as shown in Figure 6.

Mapping wildlife distributions based on denning/nesting areas and dispersal patterns is also enhanced by GPS. By taking accurate locations of den sites for species such as the Hopi rattlesnake (*Crotalus viridis* *nuntius*) and entering these into a GIS, models of dispersion, as shown in Figure 7, can be generated. This model is based on approximated distance of dispersion, habitat-use preference, and use of den sites on a yearly basis.

One of the most exciting uses of GPS is in rectification of photogrammetric information to be used in GIS. Aerial photographs, videography, and remotely sensed satellite imagery all contain distortions by taking an image of a curved surface and placing it on a flat plane. GPS can provide ground control points to give vertical and horizontal correction to help in reshaping and coordinating the image. By taking readings on the ground at locations easily recognized in the photos or by taking readings on the image, the control is established. The more control points found, the greater the accuracy of rectification. This provides a cost-effective means of mapping areas espe-

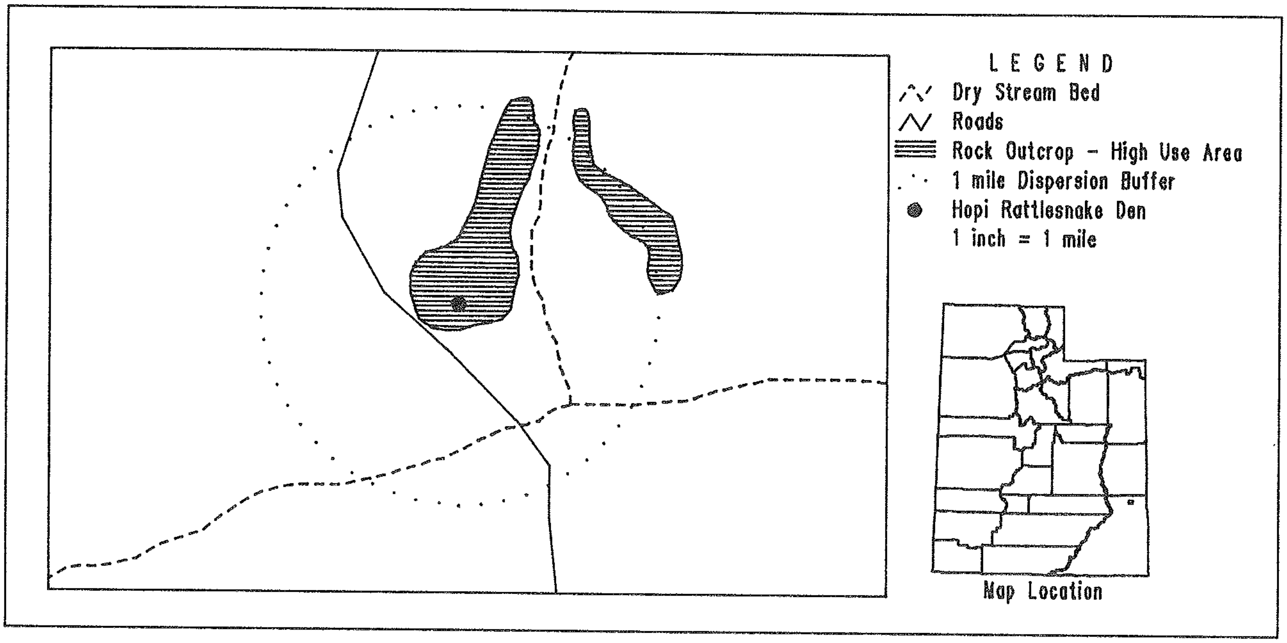

Figure 7. Hopi rattlesnake dispersion model

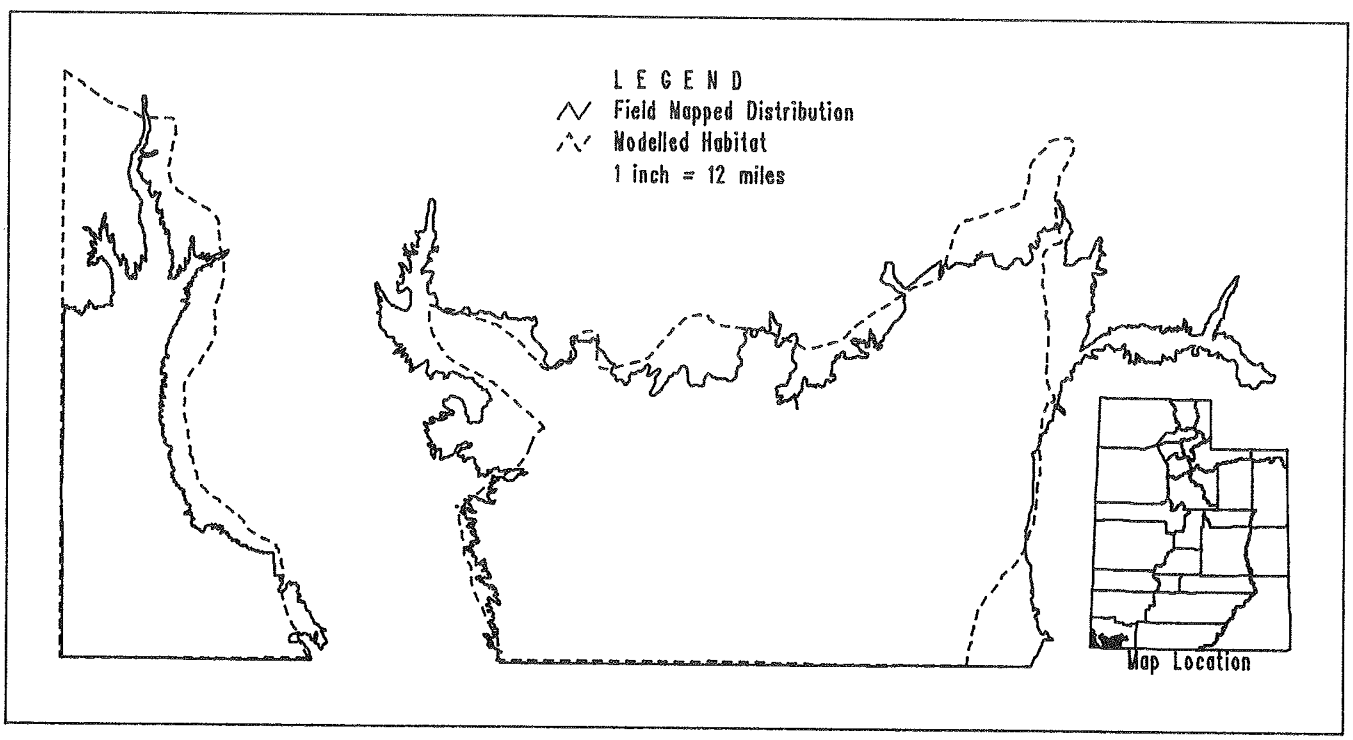

Figure 8. Comparison of modelled and mapped banded Gila monster distribution

cially in remote or poorly known areas (Hough 1992).

Using remote sensing technology, base vegetation cover maps are being developed in Utah and in many other states that will allow preliminary predictions of where individuals or groups of species may be found on an ecosystem basis. These cover maps are being developed in a cooperative project known as the Gap Analysis procedure (Foster and Schrupp 1991, Scott et al. 1990). The vegetative and land-cover types defined for mapping were selected on the basis of their ability to be seen via remote sensing and their compatibility with a regional Gap Analysis program. Georeferencing in many cases is being done by using existing GIS databases and GPS locations from field surveys.

To begin delineation of cover types, a classification scheme was developed that would fit the needs of a regional perspective and still suit the needs of resource agencies in each state. The basic component of the scheme is the dominant vegetative type that can be grouped with other types to create an ecotype (Foster and Foster 1987).

The Thematic Mapper (TM) images used for this study record information on seven spectral bands. For the Utah study, bands one to five and seven were used to obtain as much reflectance value as possible. The high gray-level values allowed increased potential to define vegetation-cover types (Craighead et al. 1985).

The TM data is stored in a raster (or grid) system with each cell or pixel containing its own reflectance value based on what was seen on the ground. Groups of pixels, usually no less than four to five, with similar reflectance are identified so that their values are not "drowned out" by contiguous groupings. By using an "unsupervised" algorithm, the basic spectral class groupings are obtainable on a statewide basis. These groups can then be identified as to cover types of interest. Field surveys were conducted using GPS to record fixed X-Y coordinates within homogeneous cover types and to establish a training for reflectance values of pixels in the TM data.

This method also provided elevation information for further refinement of data characteristics. The relief in Utah is from warm desert shrub at about 2,000 feet in southwest Utah to the alpine tundra above 13,500 feet in the Uintah Mountains of northeastern Utah (Armstrong 1977, Welsh et al. 1987). Since the reflectance values of some dominant cover types are so similar (for example, lodgepole pine vs. Colorado blue spruce), elevation, slope, or aspect information was needed to designate those cover types. The GPS information obtained in the field was used in conjunction with automated 1:24,000 scale Digital Elevation Models (DEM) to aid in distinguishing subtleties between those cover types.

By using various information on wildlife ecological relationships, these cover-type maps can then be used to generate potential distribution maps for individuals and groups of species. Mapping many of these species has never been attempted because information, such as that described, has not been available. This will be of real benefit to wildlife management, especially on ecological parameters. An example is shown in Figure 8 for the banded Gila monster (*Heloderma suspectum cinctum*) in southwestern Utah. This model shows how closely the modelled distribution from vegetative parameters coincides with the actual mapped distribution obtained from field studies.

SUMMARY

As can be seen from this brief look at a few applications, GPS can be used for a multitude of projects to aid and enhance mapping and to delineate wildlife and habitat. The use of GPS will no doubt increase as more applications are conceived, defined, and tested. Probably the most prominent limitations to the technology are (1) establishment of standards of acceptable GPS position accuracy and credibility, (2) full implementation of the GPS system by the DoD, and (3) the continual upheaval brought on by the DoD's use of Selective Availability (SA) and its attendant problems.

Still, it is safe to exclaim and promote GPS as the ultimate field tool for collection of spatial data, whether for wildlife, habitat, or other endeavors. The combination of GPS and GIS to capture, model, and analyze spatial information will save countless hours of time, will reap large dividends in dollars, and, if used correctly, will prove an effective tool in the decision-making process of managing our natural resources.

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The BLM's Remote Sensing Program in Utah

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Abstract

The objective of this paper is to outline the Bureau of Land Management's Remote Sensing Program in the state of Utah, including its evolution, structure, present and planned projects, and goals for the future. The paper will also address the challenges of establishing a new technology in the federal government and will offer viable solutions to these challenges.

BACKGROUND

Role of the Bureau of Land Management

The Bureau of Land Management (BLM) is functionally located in the U.S. Department of the Interior. BLM manages one-eighth of the nation's lands, which is roughly 270 million acres nationwide, and has the largest natural resources base under federal control, including the responsibility of managing the subsurface minerals. Most of the lands managed by BLM are located in the Western United States, although small parcels are scattered across the Eastern United States. In Utah the BLM manages 22 million acres of public land, which is approximately 42 percent of Utah's land base.

The BLM is responsible for the balanced management of the public lands and resources and their various values so that they are considered in a combination that will best serve the needs of the American people. Management is based upon the principles of multiple use and sustained yield, a combination of uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources. BLM manages to obtain an ecologically sound environment for a variety of multiple uses. The managed resources include range, timber, minerals, watershed, fish and wildlife, with BLM considering wilderness and natural, recreational, scenic, scientific, and cultural values.

The BLM has many long-term goals that include the following: BLM will improve resource conditions and prevent environmental degradation so that the public lands serve as a model for environmentally sound land-use management; BLM will strengthen research, science, and technical development efforts to accommodate the growing emphasis on global environmental issues and to incorporate proven technological developments into its program practices; and BLM will foster a service ethic that is responsive to the public and that meets the needs for public participation and information sharing.

BLM's Remote Sensing Program in Utah

The remote sensing program for BLM in Utah is located within the Automated Cartography Section of the Mapping Sciences Unit in the Division of Operations. The specific responsibilities of remote sensing include aerial photography flight planning, project coordinating, and contracting; photogrammetric applications for road updates, site plans/engineering work, contouring, and resource inventory; resource mapping utilizing satellite imagery and aerial photography; implementation of new technologies, i.e., videography; participation in the development and use of digital orthophotographic coverage; and training in remote sensing principles to other BLM employees.

Because BLM is concerned with multiple land-use management, this offers a wide variety of applications in remote sensing.

ESTABLISHING A NEW TECHNOLOGY

Overview of Identified Applications and the Remote Sensing Program

BLM's remote sensing program has taken a long time to become a reality. Prior to its being established, efforts were made for five years to acquire image-processing capabilities. Pilot projects were completed at universities to demonstrate the value of remote sensing as a resource tool, and ground work was laid for the eventual implementation of the program.

Because BLM is a conservative organization and does not have a large budget with which to work, getting people interested in remote sensing required the identification of potential remote sensing users within the BLM. Due to the nature of multiple land use in BLM, there was a diversity of operations and land-use applications. Because of this diversity, remote sensing was an attractive tool for many land-use specialists and managers.

The initial step in developing a viable remote sensing program within the "multiple use" concept was to identify several reasonable applications for the technology with potentially strong remote sensing supporters. This step was where major efforts were focused. The identified remote sensing applications are shown in Figure 1. Following identification of the applications, digital image-processing capabilities were achieved through the acquisition of a Sun workstation, Earth Resource Data Analysis System (ERDAS) image-processing software, GRASS image-processing software, and Land Analysis System (LAS) image-processing software. At this point, a projected "remote sensing program" was outlined. A two-year projection is shown in Figure 2. Initially, training and setup of the hardware/software system were the major focus along with continued identification of proven applications. Over time, training lessened significantly and identification of proven applications moved into production, verification, and promotion. These proven applications continued over time, with many projects to be completed/updated on an annual basis. Midway through the first year of program implementation, new applications were defined. These new applications were then sorted for feasibility. Viable new applications were then tested and evaluated with a reasonable pilot project. Promising pilot projects then went into production, were quality checked, and were distributed to the users. The projection for implementation of the entire program was two years. According to the trend to date, however, the program has moved much more rapidly. The program initiated in September 1991 was at about the program's one-year target goal in April 1992.

IDENTIFIED APPLICATIONS:

- FIREFUELS	*- CIVIL ENGINEERING / SITE PLANS*
- CHANGE DETECTION	*- HAZARDOUS MATERIALS*
- VEGETATION MAPPING	*- WILDLIFE HABITAT*
- SOILS MAPPING	*- LAW ENFORCEMENT*
- RECREATION	*- ROAD INVENTORY*
- ARCHAEOLOGY	*- OHV MAPPING*
- RIPARIAN	*- MAP UPDATES*
- MINING / MINERALS	

Figure 1

The program identified two types of projects: proven projects and new ideas/sampling. These project types are illustrated in Figure 3.

Proven projects go through a production phase and are then distributed. Projects that represent new, unproven ideas are evaluated, tested, evaluated again, and then produced if reliable results are obtained.

Challenges in Establishing a New Technology

Many challenges were met in establishing the remote sensing technology. The first and largest challenge by far was the issue of having to work with a limited budget. Establishing any new technology at the BLM must be cost-effective. Having the field and resource specialists convinced of the benefits in implementing remote sensing as a new technology without being given an initial budget to do so made the initial purchase of the hardware/software configuration very difficult. Although some research and development were done in each project, the primary emphasis was to be productive and cost-effective. Therefore, the second challenge was balancing research and development with actual production demonstrating proven benefits. The third challenge was educating the users of remote sensing products about the growing potential of the new technology, stressing that field work not be eliminated but better directed through the use of remote sensing. Finally, meshing the new technology within the existing framework of hardware and software configurations was difficult. Problems were encountered in trying to interface the Sun workstation with the Prime computer, BLM's standard computer. Problems also arose with interfacing the image-processing software with MOSS software, BLM's standard software. Possible difficulties were expected initially, but challenges were fully realized as projects were worked on. For example, a typical three-step process for plotting took about ten steps to complete.

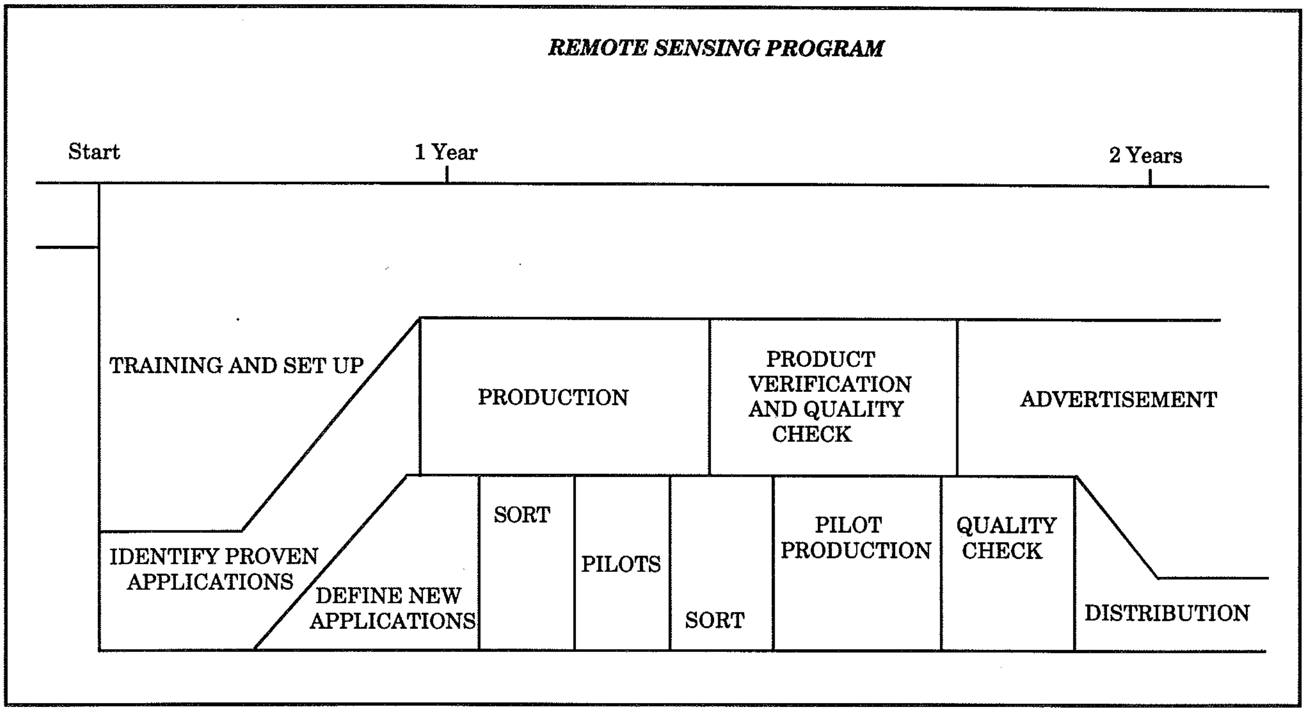

Figure 2

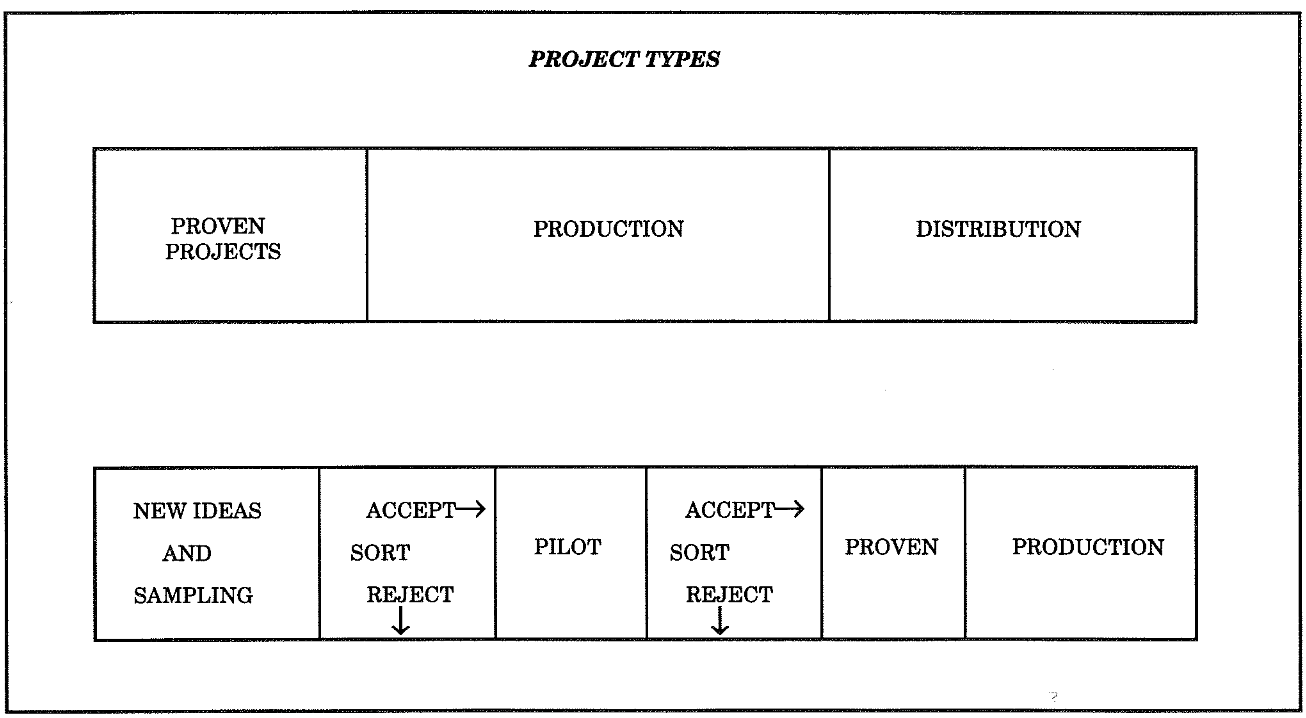

Figure 3

Identified Solutions to the Challenges

The initial challenge of having a limited budget with which to purchase an appropriate hardware/software configuration was overcome through purchase made solely by one user based on the demonstrated performance of remote sensing techniques for law-enforcement applications. The second challenge of balancing research and development with actual production will be accomplished through cooperative identification of applications with known applications and success. This is being currently demonstrated with a firefuels vegetative-cover map being produced using AVHRR data, which is based on a similar regional project done at BLM's Service Center in 1985. Once production begins, it is expected that other applications with high potential will be identified. Solutions to this challenge also include involvement with other organizations outside of BLM on a cooperative basis, with pilot projects exploring new applications. Current plans for cooperative project work include videography for riparian monitoring, law enforcement, and range-resource inventory; geological applications for structure identification and hazardous materials inventory/monitoring; map updates via digital orthophotos; Gap Analysis and other vegetative studies; soils mapping; wildlife-habitat monitoring; and change detection with older scanned imagery and new sources. Cooperative ventures are attractive because as development occurs technology is exchanged among the participants.

The solution for educating field and resource specialists in the benefits of using remote sensing as a tool will be a multitactic approach. Plans include developing hard output products and soft demos for demonstrations in-house and in the field. A newsletter will also be generated on a quarterly basis to relay technology updates as they occur. There will be personal briefings to specific state office users and potential users. Displays of output will be prepared for district and resource area offices. Finally, training classes will be presented on the field applications and user involvement in ground truthing. An important consideration that cannot be stressed enough is not to oversell the technology. It is imperative to develop and communicate a long-range plan for project development. This plan and any modifications that may have to be made as the project progresses need to be clear to all involved parties.

The final challenge of meshing the new technology within the existing framework of hardware and software can be solved by identifying current and projected needs for hardware and software. A primary source of this knowledge is through the BLM Service Center as a cooperative education venture. Additional identification of future needs can come from interaction with in-house computer support staff. A final note on this, based on lessons learned, is that anyone setting up a new remote sensing system needs to take careful consideration of various hardware/software interactions and to find out all information regarding compatibility. Types of storage media also need to be considered carefully. An example of this consideration is whether to invest in a system that supports 8-mm tapes versus 9-track tape formats. The remote sensing unit at BLM currently houses an 8-mm tape drive as well as a CD-ROM drive. Computer support staff currently use only a 9-track tape drive. To be able to utilize certain equipment, data transfers from one media to another have had to be addressed, which can be time consuming and can cause delays in production. Media choices are costly; therefore, careful preplanning is important.

PRESENT AND PLANNED PROJECTS OF THE REMOTE SENSING PROGRAM

Since the remote sensing program got under way in September of 1991, careful planning has gone into cost-effective projects. The following is a summary of some of these projects.

AVHRR Firefuels Project

The firefuels project is currently under way, utilizing AVHRR imagery. Figure 4 summarizes the objectives, advantages, and disadvantages of the firefuels project.

This project is based on a regional firefuels map BLM's Service Center did in 1985. AVHRR imagery is acquired from approximately 500 NOAA-11 images consisting of twenty-one fourteen-day maximum Normalized Difference Vegetation Index (NDVI) composites. The pixel resolution is 1 km. The data for

AVHRR FIREFUELS PROJECT

OBJECTIVES:
- *ANNUAL UPDATE*
- *CHANGE DETECTION*

ADVANTAGES OF AVHRR IMAGERY
- *COST-EFFECTIVE*
- *CLOUD-FREE IMAGERY*
- *MULTIDATE COVERAGE*

DISADVANTAGES OF AVHRR IMAGERY:
- *COARSE RESOLUTION*

Figure 4

each pixel in the composite are extracted from the daily observation scene on the basis of the maximum NDVI compositing process. Compositing AVHRR data acquired over several days produces spatially continuous cloud-free imagery over large areas with sufficient temporal resolution to study green-vegetation dynamics. There are two satellite overpasses per day, one in the Eastern and one in the Western United States. Every image that provides a clear observation of a large ground surface area at reasonable nadir viewing angles for the two-week compositing period is included in the composite. Generally there are about eighteen daily observations included in the two-week composite.

Image-to-image registration is done through a base image for reference. The base image is the USGS 1:2,000,000 Digital Line Graph (DLG). The DLG is rasterized to 1 km cells and registered to the Lambert Azimuthal Equal Area (LAZEA) map projection. Image processing is accomplished utilizing both the LAS and ERDAS image-processing software.

Presently, the NDVI data set for Utah has been subset from the United States database. Each observation period in the data set was then combined into a single composite image.

Once composited, the image was enhanced using Principal Components Analysis (PCA). Image enhancement is the process of making an image more interpretable for a particular application. Enhancement can make important features of raw, remotely sensed data more interpretable to the human eye. Enhancement techniques are often used for extracting useful information from images. Principal Components Analysis is an enhancement technique in which the number of image file bands can be reduced and new bands created to account for the most variance in the data.

The bands of PCA data are noncorrelated and independent and are often more interpretable than the source data. The first principal component corresponds to the major axis of the ellipse of data distribution.[1] This defines a new axis, and points in the scatterplot are given new coordinates that correspond to the new axis. Therefore, new data file values are derived from this process. These values will be stored in the first principal component band of a new data file. The first principal component measures the highest variation within the data.

The second principal component is perpendicular to the first principal component. The second principal component describes the largest amount of variance in the data that is not already described by the first principal component. Each successive principal component is the widest transect of the ellipse that is perpendicular to the previous components. It also accounts for a decreasing amount of the variation in the data that is not already accounted for by previous principal components.

In PCA, the first few bands account for the highest proportion of variance in the data. Therefore, PCA is useful for compressing data into fewer bands. For the firefuels map, the first three principal component bands accounted for 92 percent of the total variance. These three bands were subset to form a single image. This image was then run through a classification program to create a map consisting of forty classes.

Another angle covered was to subset elevation data for Utah from the AVHRR digital elevation model files. The source of the AVHRR DEM data was the USGS 1:2,000,000 DLGs. The elevation data were then combined with the previously derived three principal component bands. Once these were combined to form a single image, it was classified into forty classes. It was determined that the elevation data would not be used initially because the classification using the three PCA bands appeared to be more detailed. This classification will then be overlaid with vector data (state boundary, county boundaries, major roads) for ground truthing.

The vector data files were originally in the Universal Transverse Mercator map projection. This vector data was transformed into the Lambert Azimuthal Equal Area Projection to match the raster base map.

This classification map will then be overlaid with the vector data mentioned previously. The vector data will aid in the ground-truthing process. Plans exist for incorporating elevation data into the data set if significant discrepancies exist in the class identifications. Once the initial classification map is ground truthed and final vegetation types assigned to the classes, the map will be dispersed to fire personnel as well as to resource specialists needing vegetation information.

Videography

The new technologies of airborne videography and global positioning systems (GPS) have been identified as valuable, cost-effective sources of imagery for the remote sensing program. Interest lies in both natural color videography as well as multispectral airborne videography. Future applications include work in riparian monitoring, law enforcement, range-resource inventory, and hazardous materials inventory/monitoring.

At the time the initial configuration for image processing was planned for and acquired, videography hadn't been introduced to the Utah state office. Plans are being made, however, to become heavily involved

[1]ERDAS Field Guide, Version 7.5, July, 1991, pp. 98-102.

in videography applications. Videography may become the primary source of imagery for the program. Currently, cooperative agreements are being established with other agencies and institutions for participation in videography programs. Future plans include eventually obtaining "video frame grabbing" software as soon as the program can be proven useful and cost-effective.

The above-mentioned situation that occurred with videography is an excellent illustration showing that as remote sensing programs are being established it is not always possible to identify all the needs in the beginning. New needs and changes are bound to present themselves after initial implementation. This is also true of hardware/software changes that occur in a rapidly evolving technology such as remote sensing.

Riparian Applications

Riparian-oriented applications have become increasingly important at BLM over the last several years. It is an area where inventory, mapping, and monitoring have become a priority for many projects. Therefore, riparian applications have been identified as a high-potential use for remote sensing techniques.

Work is currently being done on a riparian project at Horseshoe Springs in Skull Valley, Utah, involving airborne videography and global positioning systems (GPS) correlation. This project was initially going to be done in December 1991. However, inclement weather conditions forced the project to be postponed after all the arrangements were made and underway. The field work and videography were planned to be done the last week in April 1992.

There are several objectives in this project. The first objective is to map the vegetation in the area for wildlife biology purposes. Additional objectives involve some research and development in assessing airborne videography and GPS. In the past, standard field-gathering tools for the BLM have been base maps, compasses, and other required survey equipment. Base maps typically include the 7½-minute format, 1:24,000 scale maps, and the 1:100,000 base maps published by the BLM. GPS technology is now a reality; and at the federal government level, GPS technology is planned to be used extensively in the near future. The other objectives of this project are (1) to explore the practical uses of GPS, the accuracy of GPS mediums in relation to realistic ground locations, and the benefit to be realized by field personnel and resource specialists; (2) to integrate GPS technology with satellite imagery, traditional aerial photography, and base maps; and (3) to analyze and assess the uses and advantages of videography equipped with a GPS readout as a new technology for resource studies.

Data available for the project area prior to the GPS and videography field work include base maps (24 K and 100 K scales), aerial photography at a scale of 1:3,000, traditional survey data (sixteen points), and a Landsat TM scene. Techniques that will be analyzed in this project include a ground-based survey-grade GPS unit, an airborne GPS unit, airborne videography, and airborne 70 mm photography.

The project will focus on addressing the following issues:

1. What are the coordinate readings of selected ground points using GPS, base maps, survey data, and satellite imagery? How do they compare or differ and what are the relative accuracies between the methods being analyzed?

2. How/what technologies can be used in tandem to complement/supplement each other?

3. Is a GPS coordinate sufficient for field location or is a "buffer zone" necessary?

4. What are the uses, advantages, and applications of videography for resource work?

5. What is the accuracy of producing a one-foot contour map of the riparian area using the 70 mm photography on an AP190 stereo plotter versus the accuracy of utilizing the 1:3,000 existing photography employing traditional photogrammetric techniques and methods? This project will be done as a cooperative effort with the Forest Services NFAP office and is scheduled for completion in June 1992.

Other riparian projects slated for work in 1992 include vegetation inventory and monitoring of the riparian areas along the Green and Colorado Rivers.

Minerals Applications

Minerals inventory and monitoring, geological structure identification, and hazardous materials inventory are areas in the mining and minerals sciences that have been identified as areas of interest to remote sensing.

Work has begun on a uranium mining inventory that is mandated by Washington to be completed. Utah has approximately 17,000 uranium mines (both current and abandoned) that need to be inventoried and assessed. Remote sensing plans include a variety of pilot projects using techniques ranging from SPOT imagery and traditional aerial photography to airborne videography and GPS.

Soil Science Application

Soils mapping is another area of great interest to the BLM. Remote sensing work is currently being done in the Henry Mountain and Sagers Wash areas, utilizing Landsat TM imagery. Through the experimentation of certain techniques, such as band ratioing, soils mapping via remote sensing techniques may be a viable solution in the future.

Streambed Morphology

Streambed morphology is currently being analyzed for a length of the San Juan River in southern Utah to determine shifts in the riverbed over time. Side Looking Airborne Radar (SLAR) imagery is being used in this project. SLAR has a pixel resolution of 14 m. Both near-range and far-range formats are being evaluated. It is hoped that streambeds will be delineated structurally on the radar imagery. A variety of enhancements will be done on the imagery to obtain the best results.

THE FUTURE OF THE REMOTE SENSING PROGRAM

Due to the rapidly developing and changing technology in remote sensing, the future will be challenging and exciting. As the BLM continues to develop and grow in remote sensing, undoubtedly obstacles will be encountered that will have to be overcome and solutions will have to be derived to ensure cost-effectiveness as well as quality.

The role of interagency cooperative agreements will become increasingly attractive and valuable in terms of expertise and resource exchanges; and if proposed congressional legislation of Landsat imagery occurs, the cost of new imagery will be reduced significantly, enabling more research and development to occur. BLM has established several future objectives. These are listed in Figure 5.

Of great significance to many organizations will be the long-range focus on global condition, change, and monitoring issues.

CONCLUSIONS

If there is one major point to be made, it is that change is a good thing. In order to improve our capabilities and effectiveness, we must be able to be versatile and to welcome change. In this way, advancements and achievements are made.

FUTURE REMOTE SENSING OBJECTIVES

1. *BUREAUWIDE REMOTE SENSING CAPABILITIES*
2. *PHOTOGRAMMETRIC APPLICATIONS*
3. *RIGHTS-OF-WAY DETERMINATION*
4. *GLOBAL CHANGE ANALYSIS*
   - *TEMPORAL CHANGE / ENVIRONMENTAL MONITORING*
5. *MAPPING UPDATES*
6. *GLOBAL POSITIONING SYSTEMS (GPS)*
7. *CONSISTENT BUREAUWIDE STANDARDS*
8. *INTERAGENCY EXCHANGE OF SATELLITE IMAGERY VIA EOSAT AGREEMENTS*

Figure 5

Oftentimes, we tend to sit back and wait for others to provide direction and to create our destiny. We should not just sit back and wait for opportunities to come and find us, but we should go out actively looking for them. Remote sensing has been such a rapidly changing field over the past decade that it is important to keep our eyes open and to look for opportunities and new applications. There will be both successes and failures in remote sensing, and we can always learn and improve from both. A goal at BLM is to create a network with others in remote sensing and to generate a quarterly newsletter that gives a general summary on the types of applications on which individuals are working. That way we will not keep on "reinventing the wheel." We can draw on one another's expertise and benefit from one another's experiences. That is a solution that would benefit all who are concerned with the future of remote sensing.

Copies of *Natural Resources and Environmental Issues* are available from the S. J. and Jessie E. Quinney Natural Resources Research Library, College of Natural Resources, Utah State University, Logan, UT 84322-5260. Single issues are $20.00 in the United States and $25.00 elsewhere. Please make payment with a check, money order, or purchase order, payable in U.S. dollars to the Quinney Library.

Vol. I	Riparian Resources. Edited by G. Allen Rasmussen and James P. Dobrowolski. 1994.
Vol. II	Mapping Tomorrow's Resources. Edited by Allan Falconer. 1993.
Vol. III	Conflicts in Natural Resources Management. Edited by Joanna Endter-Wada and Robert J. Lilieholm. 1994.

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